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Creative Memory Arrangement in Virtual Reality: Building a VR diary

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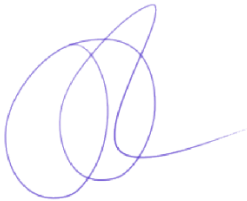Mathematics and Computer Science

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Declaration

I hereby declare that the work presented in this thesis has not been submitted for any other degree or professional qualification, and that it is the result of my own independent work.

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Abstract

In the late 2010s virtual reality (VR) devices have managed to establish themselves as a mainstream entertainment peripheral. Initially regarded as gaming-centric devices, avenues for new social interactions, collaboration and general entertainment purposes have emerged, as end-users and developers alike discover the possibilities of this generation of VR headsets. Since VR does not come with the same physical and financial limitations as physical living spaces, there is a lot of potential in simulating spaces for purposes within and outside of mere entertainment.

This study provided test-subjects with a three-dimensional multimedia diary, akin to depictions of 'mind palaces'. Once transported to such a virtual and spatial diary, subjects were given tools to shape that environment and place any number of memories in the shape of photos, videos, voice- and text notes, music, and 3D models. An experimental setup, this study aimed to find if there is potential in the idea of an immersive and creative virtual diary, in which days are represented by memory rooms, allowing the subjects to literally walk through their past to reflect and remember.

Based on usage-data and subject interviews, the potential, flaws, and strengths of this setup were analysed.

Results suggest that, while there is interest, potential and already several different ways of using such a free-form tool, the current generation of hardware is not yet comfortable enough to be worn for a longer period of time by most people, especially in order to relax and reminisce. And although the tools provided were used extensively, they were not able to facilitate many of the creative ideas of the users. Creative ideas and enthusiasm however were frequently observed.

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Chapter 1: Introduction

With the emerging technology of virtual reality (VR) finding its way into the mainstream, new opportunities for research are opening up. While mostly associated with video games today, VR has long found applications in many other fields, such as training simulations in medicine and military, as well as virtual conferences. There are also VR applications in healthcare, such as patient relaxation- and encouragement methods, in which patients are transported into a relaxing virtual environment to ease anxiety during hospital stays or surgeries (Umarji, 2020). Right now is the moment to figuratively stretch out ones feelers to explore what is possible when fully immersing oneself into new realities is as simple as putting on a hat.

The project of this thesis aims to design a virtual reality diary that brings multimedia, self-reflection, creative expression in three dimensions and a higher level of immersion together. Users are given the tools to create emotional, reflective and entertainment value for themselves. The interaction of humans with a new computer interface (VR) for means such as memory management, self-reflection, and creative expression, is a prime example of Interaction Technology research.

1.1   Background

Akin to the popular depictions of the "Mind Palace" technique, like in BBCs "Sherlock", the VR diary allows users to create a little world for themselves. The base idea is for users to create "memory rooms", with each room reflecting a single day. Over the course of the usage time, recorded days form a line of interconnected rooms that the user can traverse through while reflecting on their memories. It is a literal walk through the past. Where the mind palace, originally known as the "Method of Loci" (Mccabe, 2015), is being used as a spatial memorization technique, the VR diary allows the user to re-immerse themselves in their own memories. It is, so to speak, an emotional mind palace. The use of VR has been shown to improve on the Method of Loci (Huttner & Robra-Bissantz, 2017), when displaying a realistic setting, leading to more detailed recollection of the past (Miles, Fischer-Morgensen, Nielsen, Hermansen, & Berntsen, 2013). Adding to the pure recall of information, the goal is to enhance the recall of emotional memories and creating empathy with one's past self. It is known that not only factual memories, but also emotional ones decay over time. The brain often favours positive emotional memories over negative ones (Sedikides & Green, 2009), distorting the memory of the past. Creating an immersive memory room that reflects the mood of the respective day may diminish this effect. Aside from information- and emotion recall, there is the matter of self-reflection. While useful to many, textual descriptions may not be optimal or even usable for many who are more geared towards visual, auditive, or physical experiences. This is one reason for general data visualizations, as they can make large amounts of data easier to be perceived, to be intuitively understood, and patterns to be detected. While common data visualizations can be applied here as well (refer to Figure 17 on page 26),

3D environments in general, and VR environments in particular allow for "physical visualizations", which is defined as follows:

"Traditional visualizations map data to pixels or ink, whereas physical visualizations map data to physical form." (Jansen, Dragicevic, & Fekete, 2013)

While not strictly speaking physical, a 3D environment can simulate physicality, allowing for yet another modality to be used for the reflection on data (here: memories). Where conventional diaries are generally restricted to text (and with some effort images, if they were printed), a multimedia diary can add visual and auditive data representation. A 3D simulation however can add a simulated physical visualization. The strength of physical visualizations lies where the weakness of conventional 3D data visualization. Despite us being three-dimensional beings, 3D data that is projected onto 2D screens is often difficult to navigate or to be perceived accurately. It is also outperformed by physical 3D data, as there is no distracting layer of abstraction (Jansen, Dragicevic, & Fekete, 2013). Removing layers of abstraction and moving data, in this case memories, into a semi-physical realm that requires less cognitive work to be understood may yield similar benefits, allowing users to experience their past in a more intuitive way. Where visualizations can make data easier to understand, flexible modalities and physical visualizations may uncover ways of interpreting memories and interacting with oneself.

1.2 The Vision

In the second book of the Harry Potter novels series, Harry finds a magical diary. He opens it and finds it being able to not be read, but to speak. When asking questions about the ominous *Chamber of Secrets*, it answers that, yes indeed, it knows about that long-lost secret. Not only that, but it can also *show* the boy what had happened at the wizarding school 50 years ago. It transports Harry into the world of the past. People in that past reality can neither see nor hear him, and he cannot touch anything either. But he can observe, he can experience the memories of the mysterious Tom Riddle, the previous owner of that diary. Harry feels the frightful atmosphere, he sees the people through Riddle's eyes and experiences the intensity of past conflicts. And the diary knows just what to show him, based on his questions. It is an experience beyond mere words.

Now, in the above-described example, the purpose of the diary was to be found, to be experienced by a third party. That aspect is not part of the vision, neither is the sinister spirit lingering inside the diary, trying to kill children. But aside from that, Riddle's diary has a lot of interesting features that today's technology may be closer to being able to replicate than one might think. While autogenerating the complete 3D surroundings from our past may be out of reach, an interactive diary, being able to retrieve memories based on user-queries, able to combine visuals, sounds and text, as well as producing fully rendered 3D surroundings is not. Being transported into a new reality is possible now, barely lacking behind the experience Harry had, the hardware required for that is affordable for most people today.

The vision of this work is to create such a diary, to see how far we can go today, even with limited time and resources. It is a diary that creates a reflection of the past, the world, the memories.

1.3 Motivation

Given my past academic work, motivations, and passion projects so far, a thesis project such as this was almost a foregone conclusion. My first software project was a user interface builder. During my high-school years and early university education I developed a 3D scene editor and soon-after wrote my bachelor's thesis about the requirements and challenges of implementing a world-scale Augmented Reality for digital maps. Lastly, during a recent internship, I created a proof-of-concept for an automated web-application generator that builds an interactive interface from a list of input- and output requirements. To summarize: The creation of tools that allow others to be creative, as well as the combination of automation and creativity, has fascinated me for most of my life.

Furthermore, I've had a long-time interest in creating virtual spaces that, unlike current social media platforms, are not meant to be used performatively and for outward self-presentation, but for going inward and creating a personal space that is not limited by financial or spatial circumstances, and not held back by the creator's fear of being perceived unfavourably by others. With all of that in mind it comes to no surprise that my chosen research project contains and editor for virtual spaces, an immersive VR world as a creative playground and a malleable environment meant as private and limitless retreat. The most interesting part of this project was seeing if and how people want to use it.

1.4 Research Questions

During the planning phase of this project, two initial research questions were formulated and to be answered by the experiment:

1. **Can creative spatial memory arrangements in VR be more effective than conventional diaries?**

"More effective" meant that users might be more motivated to self-reflect, be able to be more empathetic with their past self, score higher on the SRIS (Self-Reflection an Insight Scale) or have a better recall of past events. While "effective" was meant to be broad and stand for any kind of improvement over conventional diaries, interviews with participants very early on suggested that the search for a "better" diary experience might be misguided. It is naive to assume that the conventional paper-based diary is lacking something that a new technology will fix. Rather, a new technology might introduce additional value. The same way videogames introduced interactivity and creativity where movies did not, they did not replace them, but simply added value to people's lives in a different way. Similarly, the focus of this thesis shifted from building a "better" way of keeping a diary to a different way of keeping a diary. The aim to find new ways to generate value for users remained the same, but rather than competitively measuring

performance between the different types of journals, this research aims to find if virtual diaries can create new value. Furthermore, the wording on the first question was too broad, necessitating the testing of every possible VR diary implementation before being able to answer it. The second research question was similarly flawed:

2. **Can software analysis of memories (discovering connections, extracting entities and moods) enhance the experience and generate further insights for the user?**

This research question was formulated with the many powerful tools and algorithms in mind that can find statistical trends in data, such as mood shift patterns or correlations in high dimensional data that a human would not spot. At the same time, multimodal media analysis could play a major role when participants create photos, videos, audio recordings or text entries. While initially seen as a second standalone research question, it became clear during the experiment that it is merely an example of the additional value to potentially be found, thus rather a sub-research question to the first one. Thus, quite late during the testing phase, the research question shifted to:

How to design a VR diary that allows people to generate value for themselves?

This research question does not imply a strict "effectiveness-score" to diaries, which is unrealistic, while allowing for the discovery and discussion of the different kinds of value users of this software may find.

1.5   Project Execution

This thesis project started in September 2020, after the conception of the base idea, with the creation of a simple proof of concept to show the idea could be implemented using today's technology. In October, a pre-test playthrough was conducted, in which participants gathered memory files over the course of multiple days, as if they were planning to use them in a multimedia VR diary. The subsequent interviews of participants gave insight into user demands and reservations and were used as guidelines during development. The following six months were spent researching adjacent topics, such as VR interaction design, diary methods and self-reflection, as well as the development of the VR diary. In late February, a demonstration video was published to recruit participants with testing beginning in early May and concluding at the end of July, at which point the writing of the thesis was well underway. The data analysis and finishing of the thesis took place in the first week of August 2021.

1.6   Thesis structure

Chapter 2, *Technology Review* and Chapter 3, *Literature Review* build the knowledge used to create the VR diary software, described in Chapter 4, *Implementation*. Chapter 5, *Methodology*, explains the methods for the test execution, the results of which are described in Chapter 6, *Findings,* and analysed in Chapter 7, *Discussion*. Chapter 8,

Conclusion, reflects on the knowledge gained in this thesis, critically reviews the project, and elaborates on future work and improvements.

Chapter 2: Technology Review[1]

This chapter reviews the development and current state of virtual reality systems, based on which the hard- and software platforms for this research were selected. These current and past developments are also worth noting when attempting to predict future trends and developments. Furthermore, current- and similar VR software is reviewed and compared to this project.

2.1   The State of VR

Virtual Reality as a concept has existed for many decades, going back as far as 1961 with the "Sensorama" (see Figure 1) and slowly started to evolve in academia, e.g., through the head-mounted 3D display of "The Sword of Damocles" in 1968 by Ivan Sutherland.
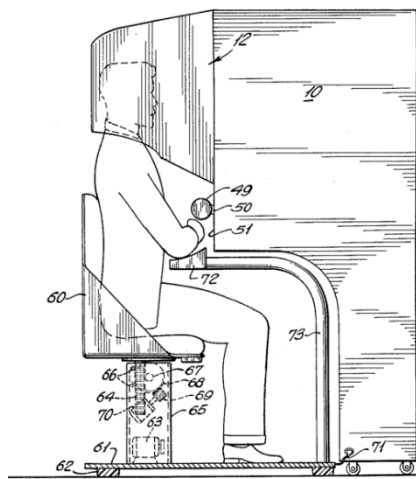
Figure 1: Sensorama (Morton, 1961)

Seen as embryonic gimmicks in the public eye, VR headsets only started to gain traction in the entertainment mainstream in 2013 with the release of the *Rift* headset by Oculus VR. Since then, other major technology corporations, such as Valve, HP, HTC and Sony, have released their own VR devices, which are now established brands. While these first

Figure 2: Samsung Gear VR (Pesce, 2014)

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[1] Partially taken from the preceeding research report (Rosenbusch, 2021)

generations of modern VR headsets were static installations (meaning a movable VR headset wired to a computer), recent years were marked by the rise of mobile VR. The Samsung Gear VR, first announced in 2014 (see Figure 2) and developed in collaboration with Oculus, introduced portable VR experiences to mainstream users, who could insert compatible phones into the headset, handling the computations, meaning no wires to a stationary computer were required. Using smartphones, which are rather limited in terms of processing power in comparison to stationary PCs, meant that users would get a very low-end experience of virtual reality, with less immersive environments and lower-end graphics than with devices wired to a PC.

Still, the then-CTO of Oculus and driving force in the videogame- and VR industry, John Carmack, predicted:

"[…] mobile technology is going to be the dominant platform. […] The VR headset of our dreams does not have wires on it, it is probably going to be built out of more mobile technology. But that VR headset of our dreams is not here now and isn't going to be here in the next couple of years." (Carmack, Keynote: The Dawn of Mobile VR, 2015)

In the year of 2020, this prediction proved to be accurate, as Oculus released the popular successor to their standalone *Oculus Quest* headset, only a year after its initial release. Essentially a heavily modified Android phone, the Oculus Quest significantly narrows the gap in terms of graphics and immersion to a PC-tethered headset and will likely continue to do so with coming versions. In his 2020 keynote, Carmack confirmed the standalone Quest headsets, which can optionally be plugged into a PC for higher processing power, to replace purely PC-tethered headsets in the future (Carmack, 2020).

Currently, VR is mostly used for gaming in the mainstream, however Carmack further predicted mainstream virtual reality to become "bigger than gaming". Large portions of the population would use VR for creative tasks or socializing and only end up playing games in VR as a side-effect, rather than gaming being what pulls them in. Speaking from his own experience with his mother taking and viewing 360-degree panoramic vacation photos, Carmack noted:

"[…] we're going to be surprised how many people that we would not expect to be caring about virtual reality wind up picking up things like this" (Carmack, Keynote: The Dawn of Mobile VR, 2015).

2.2   VR Principles

Of the different types of VR and other mixed realities, a standalone, 6DoF device was chosen to be the focus of this thesis. 6DoF stands for six degrees of freedom and describes the set of movements the device can track. This means that the headset can track both movement and rotation, each in three dimensions (see Figure 4). In contrast, 3DoF (three degrees of freedom) headsets only measure the rotation in three dimensions. The user's

turning of the head is translated into the simulation; however, they cannot freely move around.

A 6DoF headset tracks the user's movement with of a variety of sensors. This way they can precisely map the user's translation and rotation to a virtual camera that looks out onto a virtual scene. If a low-enough latency between the movement of the user's head and the virtual viewpoint and display update is achieved, the user will have the impression of being physically present in a virtual environment. There is a wide variety of sensor arrangements to provide 6DoF measurements, usually consisting of IMUs and cameras. IMUs (Inertial Measurement Unit) are responsible for measuring a body's physical state and movement. The IMUs of virtual reality devices generally rely on accelerometers (for tracking acceleration) and gyroscopes (for tracking rotation), aided by visual tracking by
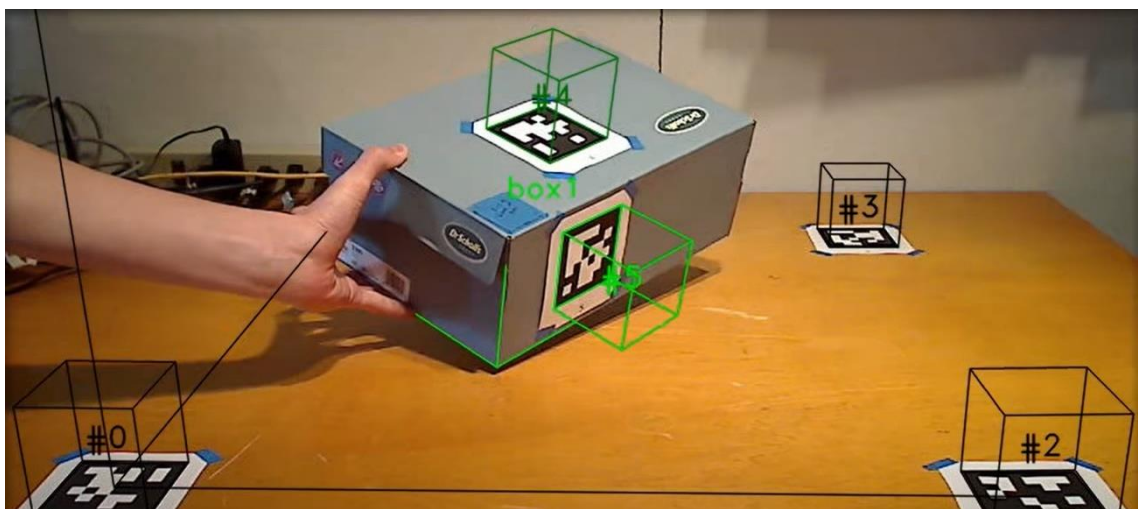
Figure 3: Marker-based tracking (April Robotics Laboratory - University of Michigan, 2012)

cameras.
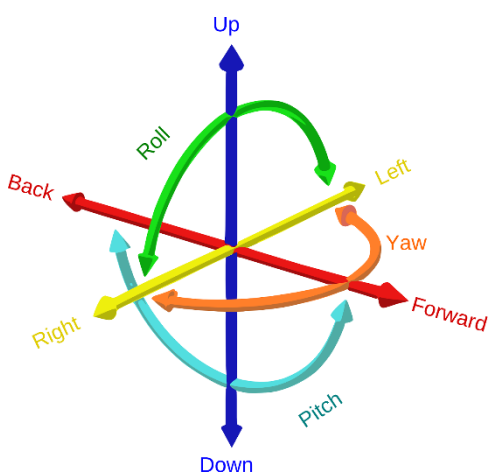
Figure 4: The six degrees of freedom (GregorDS, 2015). The Up/Down, Forward/Back and Left/Right axes represent movement in 3 dimensions. The Roll, Pitch and Yaw represent rotation in 3 dimensions, adding up to 6 degrees of freedom (6DoF).

Visual tracking works in one of two ways: Inside-out tracking and outside-in tracking. Inside-out, as used by the Oculus Quest headset, means that cameras are directly attached to the VR device to track motion through the shift of visual markers. A visual marker can be a pre-defined image (e.g., a sticker) on a wall, or a visual point of interest that was found during runtime. Predefined markers are useful to improve tracking in environments that are otherwise plain, like an empty room with white walls or another such plain surface. They do, however, require preparation and are only useful when they are in line of sight. Therefore, their usage is generally restricted to being a trigger in AR (Augmented Reality) applications to show 3D visuals at a

specific location (see Figure 3), or to help the device locate itself, if it knows to associate specific marker images with specific locations. Common VR devices that employ inside-out tracking do not rely on visual markers but dynamically find and track visual points of interest over time.

Outside-in tracking, as used by the HTC Vive headset, relies on external trackers, arranged around the space the user will move in. While this requires more effort during setup and is a less portable solution, it has the advantage of a higher accuracy and less latency. When choosing between devices using inside-out and outside-in tracking, one should generally go for outside-in for the most high-end experience and inside-out for convenience.

Aside from the headset there are the user input devices. While hand-tracking is coming to the Oculus Quest 2, most user interactions in VR either come through controllers (see Figure 5) like those of video game consoles, or, on VR-capable smartphones, through a gaze control. Gaze control means that users interact with elements by looking at them. That has the benefit of not requiring controllers, it is however slow to use and limited to simple actions. For the most accurate input, controllers are currently the best option, as hand gestures rely on visual algorithms and are thus far more error-prone and inaccurate. Furthermore, controllers are intuitive to people accustomed to video game controllers, and, to a lesser degree, also to people accustomed to TV remotes.

Figure 5: Controllers for the Oculus Quest

2.3   Device Selection

Theoretically, multiple versions of the same software could have been written to run this experiment cross-platform on all major VR headsets to reach the largest possible number of participants, this however was not within the scope of possibilities for a one-manned thesis project on a schedule. When choosing which device to develop for, there were three factors to consider.

1. Peripheral Quality

Whether 2D or 3D, videogames or real-life captures, a certain amount of suspension of disbelief is always required to immerse oneself into any kind of content. Videogame enthusiasts needed but a few moving pixels on a black screen to immerse themselves into fictional worlds even back in the 1970s. However, the higher quality the visuals, the less suspension of disbelief is required and the higher the immersion that can be achieved. Since the goal is to immerse the user in their own memories, a higher quality peripheral is preferred. However, no far-looking photorealistic scenes, complex light effects or

physics-based simulations were used, as that would require effort and funding outside of the scope of this project. High processing power (generally only available by tethering a headset to a PC) is thus not of high priority. Having sufficient random-access memory (RAM) however, which is needed to display many memories (especially high-resolution photos and videos) simultaneously, is crucial. Another factor relevant for visual quality is the screen resolution. On older generations of modern VR headsets, single pixels are visible. Generally, the higher the screen resolution the better.

Another aspect of peripheral quality is the (dis-)comfort of the wearer. Heavy headsets put strain on the user's neck and face and low refresh-rates and poor motion-tracking can lead to nausea and headaches. These aspects are more critical than raw visual quality. However, participants in this experiment were not expected to wear their headsets for long periods of time (rather 10-20 minutes a day). Still, if the headsets are too uncomfortable to wear for even short periods of time, less user engagement is the logical consequence.

2. Ease of Use

Since keeping a diary is a repeating activity, it is of high importance to keep the effort on the user as low as possible. In an optimal scenario, the user puts on their standalone headset and is ready to go immediately. In a less optimal setting, the user might have to connect their headset to a PC first, boot the PC, start the application, and then put on their headset. In the worst-case scenario, the user would even need to set up additional hardware that keeps track of the headset's transformation. While setting up such external trackers is a one-time effort, it does complicate the setup and restricts users physically.

Furthermore, requiring a PC to be connected to the headset means the user would need to be provided with a strong-enough machine to handle virtual reality. Most participants would end up having an additional PC or laptop set up in their home, taking away space and requiring them to learn to handle that machine. This would require an even more complicated setup and a steeper learning curve. Not only would the user experience be worsened, but also the pool of participants to choose from would be limited by their available space at home and proficiency and patience with using computers. It would also require the researcher to provide participants with such computers, adding further risks and expenses whenever the hardware had to be sent and putting even more strain on the university. For these reasons, ease of use was of a higher priority than peripheral quality.

3. Availability

Since this research does not receive any funding, it was limited to what the Human-Machine-Interactions Lab of the University of Twente was able and willing to provide, plus any personal expenses the researcher was willing to make.

Knowing these priorities, the next step was to take inventory of which headsets could be provided by the university. Table 1 lists the VR headsets in the HMI Labs inventory as of

the time the implementation phase began (assuming a VR-ready PC provided to participants would have at least 16 GB of RAM).

Device Name	Type	Resolution per Eye	RAM	Weight
Oculus Quest	Standalone (Android)	1440 x 1600, 72 Hz	4 GB	571 g
Oculus Quest 2	Standalone (Android)	1832 x 1920, 120 Hz	6 GB	503 g
Oculus Go	Standalone (Android)	1280 x 1440, 72 Hz	3 GB	468 g
Valve Index	Tethered (external trackers)	1440 x 1600, 144 Hz	16 GB	809 g
HTC Vive	Tethered (external trackers)	1080 x 1200, 90 Hz	16 GB	470 g
HTC Vive Pro	Tethered (external trackers)	1440 x 1600, 90 Hz	16 GB	555 g

Table 1 Available VR Headsets at the University of Twente

Due to the high priority of ease of use, the Oculus Quest 2 (see Figure 6) was chosen, as it is the most high-powered standalone headset available, while also being among those with the highest resolution. Using the tethered HTC Vive and Vive Pro (as they are similar enough that no or very little additional implementation effort is to be expected) was considered as well in order to have more devices and thus increasing the number of participants. However, some of the Vive headsets were already in use by other students and the high additional effort both on the side of the participants and the researcher was not deemed worth having a few more datapoints.

Figure 6: Oculus Quest 2 Headset and Controllers

2.4 Similar Projects

To avoid reinventing the wheel (or at least make sure to invent an improvement over an existing wheel), similar projects were looked for, both within and outside of the context of VR. At the time of writing, no VR diary software with comparable features could be found. There are, however, numerous diary- and diary-like applications, feelings- and period trackers, memory tools and therapeutic apps, especially for smartphones.

Many of these applications have their own set of possible feelings to note, activities to report and goals users can set. The self-improvement app *LifeRPG* (Life Role Playing Game) for instance uses gamification and allows users to define their own skills they want to improve and visualizes user-reported progress for each goal. During usage, the app will provide positive quantifiable and visual feedback on progress, like a check-off to-do-list, the filling of a progress-bar or a rising graph.

Moving on to less entertainment centred and more statistically driven apps, the *Pixels Mood Tracker* and *Mood Patterns* apps provide users with graphs and detected patterns in a number of data visualizations. There are rasters, color-coded (by mood) calendars as well as different graphs to show changes over time. A more specific and hugely popular type of apps are period trackers, which help people with periods keep track of their cycles, when to expect their next ovulation, when PMS will set in and when they are most and least fertile (see Figure 7). They also incorporate functionality to track moods and physical complaints.

CBT Thought Diary on the other hand wants users to revisit specific memories and is less concerned with statistical analysis, thus a bit closer to the idea of this project. Users can create events and memory notes. It is very diary-like and quite efficient by explicitly asking the users for their emotions for each memory note, which is a much faster way to express feelings than formulating entire sentences in plaintext.

Similarly, there are a lot of dream diary apps, most of which follow a similar pattern. Users can create dream entries, give them a title, a description, several tags to easily find similar dream entries and one or more emotions felt during or after the dream. The use of tags is quite interesting and potentially powerful, especially with a large data set.

Figure 7: Variety of period tracker apps in the Google Playstore

Worth mentioning are also chatbots such as *Wysa*, designed to be therapeutic and handle topics such as trauma, loss, loneliness, stress, and discrimination. It plays a very active role in the user's self-reflection by asking specific questions and giving prompts for topics to speak about. While this research-project does not aim to provide therapy, some of the designs and mechanics of the chatbot are interesting in how they try to evoke the user to elaborate on their feelings and experiences. For instance, by suggesting broad topics to reflect and write about, users might be helped remembering events that had transpired but already slipped their mind. In general, many of these apps try to provide constructive feedback on the user's way of life. This will be avoided entirely in this project. The author of this thesis has neither the qualification nor intention of providing feedback about lifestyles or choices. The goal is aiding people in self-discovery, not telling them what to do.

Last come the memory tools and mind palaces. As the name *mind palace* suggests, these applications are built on the method of loci, which is not meant for journaling or self-reflection, but for associating objects and locations with memories to memorize facts. *Memorypalace.com* is a 2D tool for the web browser in which users can share their memory palaces (in the shape of single rooms) that help remembering certain facts. There is, for example, one shared room to help users solve a Rubik's Cube, one to help memorize Human Body Systems and so on. While it was interesting to see what people try to remember, this tool has very little interactivity and is also technologically not related to the idea of this project. *Munx VR* on the other hand is very closely related in terms of technology, as it allows users to create their own 3D spaces in VR by dropping 3D models into the scene. Interestingly, it uses the same combination of 2D and 3D interfaces for object placement and manipulation that is planned for this project (see Figure 8). When contacting the developers, they stated to have used the Unity3D engine for development and that there had not been any pre-existing mechanisms for their UI design, requiring them to spend a lot of effort on implementing an interface from scratch.

2.5 Conclusion

Gone are the days where virtual reality headsets were a fringe technology, only
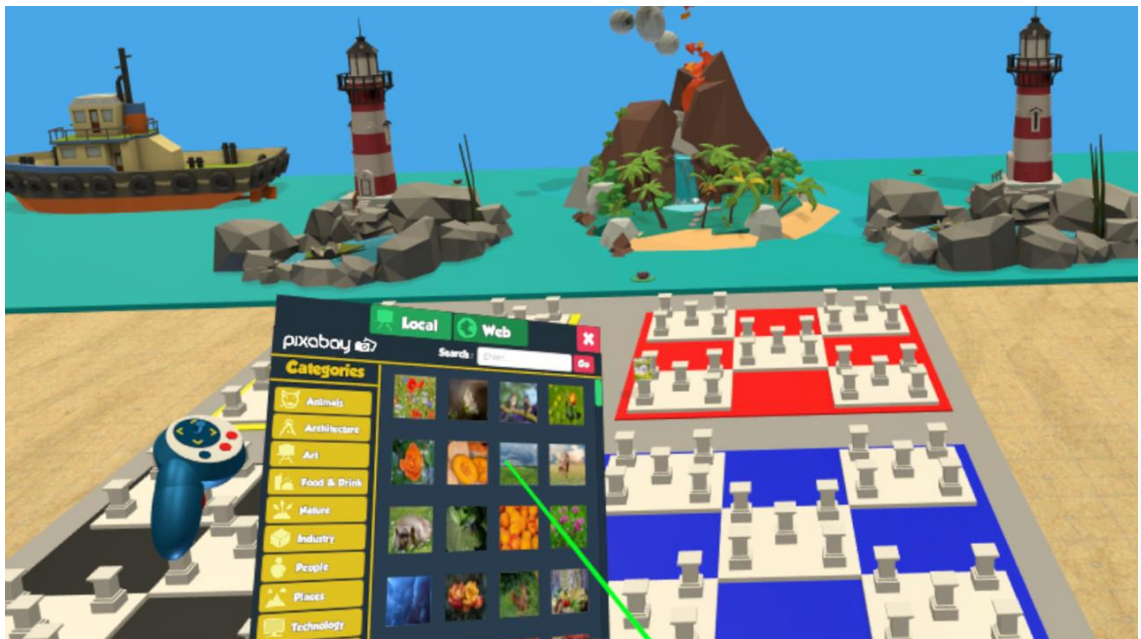
Figure 8: A scene from Munx VR, in which players can browse a catalogue of 3D models to build mind palaces (Linguisticator-Ltd, 2018)

impressive in theory and of little value to mainstream consumers. Where before every headset brand released their own versions, which were as extremely different as they were extremely immature, current generation headsets are approaching broad mainstream appeal. They have matured over multiple iterations, showing a long-term commitment by their manufacturers, while converging on a platform-independent standard. This means that, at least for PC-tethered headsets, most games or simulations will not need to be custom made for their specific hardware.

For this project, the Oculus Quest 2, which is the (as of September 2020) most modern standalone headset, was chosen, as it performs well enough for the task at hand while saving both the researcher and the participants a lot of effort.

While no project similar enough to be used as a basis was found, search for similar applications resulted in the idea of using tags to connect memory objects with each other and to provide some feedback to the participant as a kind of reward.

Chapter 3: Literature Review[2]

Broad research on topics touching on diaries, self-reflection and usability aspects of virtual reality experiences was conducted. This chapter, divided into the sections *Diaries* and *Virtual Reality Experiences*, presents, and merges the research findings. The resulting research question itself underwent a transformation during the execution of this study, discussed in section 1.2.

3.1 Diaries

Diaries are a popular method of capturing one's mental state over time and going inward to self-reflect. It would thus be intuitive to assume that diary-keepers are more self-aware and possess a lot of self-insight, given that they invest more time in analysing themselves. As this study tests a new form of self-reflecting and capturing one's mental state, diaries, as in their function and their application in science, are of high interest.

3.1.1 A quantitative measure of self-reflection

Since this is an exploratory project, and thus to a degree a shot in the dark, a quantitative way of assessing the effectiveness of a VR memory space was researched. The quantitative "Private Self-Consciousness Scale" or PrSCS (Fenigstein, Scheier, & Buss, 1975), more recently succeeded by "The Self-Reflection and Insight Scale" or SRIS (Grant, Franklin, & Langford, 2002), have been previously researched. The older measure suffered from inconsistent performances and was likely to tap into unproductive rumination and self-absorption, rather than self-awareness.

Reading up on the newer SRIS, a score calculated from a series of Likert scale questions, the first expectation was to find a straightforward way to quantify self-awareness. The second expectation was to find high values in diary keepers and mixed-to low values in those who do not spend significant time self-reflecting. Both assumptions turned out to be wrong. Grant et al. (2002) found that they needed to split the scale into two values, namely self-reflection (SRIS-SR) and insight (SRIS-IN). Judging by their studies, there is a clear correlation between the need of self-reflection (to gain insight) and SRIS-SR. They did not find that a higher score in SRIS-SR results in a higher SRIS-IN, or vice versa. This shows that self-reflection does not automatically lead to more insight, but they did find evidence that it can lead to more self-absorption and rumination, as seen by the flaw of the PrSCS. At the same time, individuals with a lot of insight into their own behaviour might not feel the need to document and analyse their feelings.

The two scales of SRIS are an asset that takes these facts into account. SRIS-IN correlates negatively with depression, anxiety, and stress and positively with cognitive flexibility and self-regulation. SRIS-SR on the other hand does not correlate with cognitive

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flexibility, self-regulation, and depression, but positively with anxiety and stress. It does, however, not suggest that the mere act of self-reflection is the cause of these. Another study in the same paper compared people who keep diaries with those who don't and found that SRIS-SR correlated positively with diary keeping, SRIS-IN however showed a slight negative correlation. Specifically, anxiety was more commonly found in diary-keepers. It bears mentioning that this particular test was conducted exclusively with undergrad psychology students (mean age of 23 years), with a heavy gender-bias (99 out of 121 subjects were female).

Concluding from this research, it is possible to use SRIS-SR as an option to compare scores before and after the test, but it will not tell us if the VR Rooms is more effective than an old-fashioned diary. It will however show whether the self-reflection of participant has increased at all. To show an advantage of VR Rooms over conventional diaries would be an increase in SRIS-IN.

3.1.2 **Diary Studies**

Moving on from the potential outcomes of keeping a diary, there is an entire field called "Diary Studies", which can very simply be explained as follows: "In diary studies, people provide frequent reports on the events and experiences of their daily lives" (Bolger, David, & Radaeli, 2003). Diary studies allow to not only consider specific values of pre-selected measurements, but also "little experiences of everyday life that fill most of our working time and occupy the vast majority of our conscious attention" (Wheeler & Reis, 1991). This experiment is in part a diary study, albeit a free-form one, in which the reports take the shape of creative expression. To be clear: This is not a pure diary-study, but shares some of their characteristics, which is why the rest of this section will summarize the fundamentals of diary studies and elaborate on the choices to be made in designing them.

Diary studies are used to report changes in subjects over time. They are often used because of their two main advantages over laboratory tests. The research during a diary study takes place in the context of the subject's daily life, meaning they are likely to give a more accurate impression of the subject's inner state (Reis, 1994). Laboratory environments and other deviations from a subject's normal routine are likely to introduce distractions, stress and other factors that will distort the subject's behaviour and state of mind, and thus the results of an examination. This is comparable to a blood-pressure test taken at a doctor's office, that finds a high pressure, simply due to the patient's anxiety from being at the doctor's office, or due to their fear of finding that something is amiss (a self-fulfilling prophecy). Was a blood-test however taken in the patient's home, without them even being aware of it, the results would be less error-prone. The same likely applies to diary studies in comparison to laboratory experiments.

The second major advantage is the dramatic reduction in the likelihood of information decay (Bolger, David, & Radaeli, 2003), since only a short amount of time passes between

the occurrence of a relevant life-event and the reporting thereof. It is for that reason that the VR diary did not allow subjects to add to, remove from or alter their past recordings but only give them editing tools for the current day.

Bolger et al. define three types of research appropriate for diary studies:

1. Obtaining reliable person-level information
2. Obtaining estimates of within-person change over time, as well as individual differences in such change
3. Conducting a causal analysis of within-person changes and individual differences in these changes

This experiment will touch on the second of these types. Instead of asking participants for a summary of a recent period (here: a week), the data is automatically generated as they use the software, avoiding the worst of information decay.

Following the research types, Bolger et al. introduce three categories of diary studies, namely:

1. **Signal-contingent design**
   A signal (automatically, randomly or by choice of the researcher) is given, prompting the subject to create a diary report.
2. **Event-contingent design**
   A predetermined event (emotional or physiological triggers, etc.) occurs, after which the subjects know, they are required to create a diary report.
3. **Interval-contingent design**
   The subject reports their state as part of a predetermined routine (e.g., at the end of each day).

Additionally, Jannsens et al. (2018) name further choices to make when designing a diary study. The subject pool may or may not include individuals with mental or physical illnesses. The diary report may be momentary, retrospective or both. Lastly, there is the number of items the diary report should assess and the overall study duration. As stated before, diminishing the information decay observed in reporting information retrospectively is one of the main reasons for choosing diary studies, however, the advantage of retrospective reporting of longer time periods is putting less effort on the subjects. A balance must be found to diminish information decay as much as possible without wearing down the subjects by constantly asking them for new diary reports.

Similarly, a balance must be found in the number of items a diary entry should contain, or questions that need to be answered. The more items, the more information can be extracted, however, it does come at the price of additional effort for the subject. And finally, a balance also must be found for the study duration. More datapoints generally lead to more valuable results, then again, the longer the testing period, the more the subject's performance may dwindle, and the fewer subjects may be willing to participate in the first place.

Interestingly, Janssens et al. found that, out of 47 researchers that employed diary methods, 40% were not satisfied with their study design in hindsight, most of them stating they would intensify the study (shorter timespans in-between reports, adding more items or lengthening the testing periods).

As for the assurance of quality of data coming from diary studies, Thiele et al. (2002) define several steps that can be taken. Firstly, the method of diary taking must be simple, easy to understand and adjustable to the participant as not to overburden them. Subjects must also be given an introduction to avoid confusion, and it is also advised to run trials under supervision to spot common problems subjects may have. Since diary studies tend to be time-demanding, a compensation is recommended. To avoid subjects quitting the testing procedure, the researcher or research assistant should be approachable in case of complaints or difficulties during execution. Lastly, Thiele et al. recommend to regularly but unexpectedly contact subjects to inquire about the proceedings of the tests.

3.2 Virtual Reality Experiences

While the concept of virtual reality headsets as used in this study dates back decades, they have only recently been met with success and are even now far from being as mainstream as smartphone, gaming consoles or PCs. Usage data, especially open-source data, is thus scarce and many lessons on best practices are yet to be learned.

3.2.1 Comfort Concerns

There are two main comfort issues for current VR devices that lessen the enjoyment, or, at worst, might lead subjects to decide to withdraw from the experiment.

3.2.1.1 Sensory Irritation

An online survey with 292 participants found that around 57.7% of people at some point experience what is known as VR sickness, which reportedly shares symptoms such as nausea, eye fatigue and disorientation with motions sickness (see Figure 9) (McCauley & Sharkey, 1992; Nguyen, Lake, & Santiago; LaViola, 2000). Additionally, during first
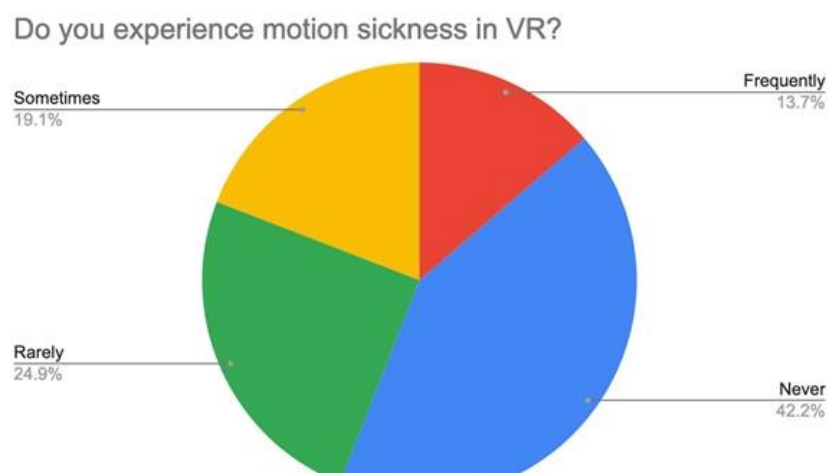
Figure 9: VR Motion Sickness Statistics (Nguyen, Lake, & Santiago)

tests with the Oculus Quest 2, the author of this paper found it could also lead to a short and mild headache. To avoid subjects withdrawing from the experience and being hindered in their creativity, measures will need to be employed to lessen this effect.

Motion sickness occurs when sensory inputs contradict what is expected or what the body is used to. In daily life, this can occur during turbulence on a flight. The exact cause and workings of motion sickness are not yet entirely clear (Sherman, 2006). One common explanation is that of a sensory conflict. It suggests that the more predicted the sensory input about the body's movement, the less motion sickness tends to occur (Watt, 1983). This does explain the cause of VR sickness, since the body's sense of balance will sometimes not confirm the motion shown by the virtual camera moving through a virtual environment (for instance when joysticks are used for movement). Another source of irritation is that different people have different distances between their eyes, also known as the IPD (interpupillary distance) which the hardware will need to account for. Some headsets, like the first Oculus Quest, provide a sliding mechanism that allows the user to accommodate their IPD very precisely, eliminating or at least minimizing IPD related issues.

To lower the likelihood and severeness of these effects, attention will need to be paid to keeping the framerate as high as possible, since a delay between a subject's motion and appropriate change in the visuals will likely cause sensory irritation. This will come at the cost of lower grade graphics, the quality of which directly correlates with the framerate. Furthermore, the media uploaded to the headset by the user will need to be processed in such a way that enables the VR application to visualize them without a high performance impact. Photos and videos need to be downscaled (i.e., their resolution needs to be lowered) and thumbnails (low-resolution versions of images) need to be employed wherever possible. Further strategies for minimizing computational power required and memory consumption will be explored in chapter 4.

3.2.1.2 Discomfort of wearing a headset

Wearing a helmet is uncomfortable. Even wearing over-ear headphones can cause irritation and headache after a longer period. It comes to no surprise that weight and ergonomics play a major role for VR headsets. In terms of weight, current popular VR headsets range from 470 g (HTC Vive) to 809 g (Valve Index). The issue of weight is not primarily the strain on the neck, but rather strain on the face when the headset is not well balanced. Different VR devices employ different ways of fastening to the head with the general goal of avoiding a lot of strain on the head and especially face. At the same time there should not be a lot of wiggle room. A loose headset will not maintain the optimal position of the lenses with regards to the eyes, distorting the image or even cutting it off. Putting on a VR headset the optimal way is not always straightforward and will likely require users to be assisted to ensure that they won't be plagued with headaches, too much weight resting on their cheekbones or a loose headset. Generally, the longer the usage time the more discomfort. The minimum time required to spend in VR should thus be

brief, so that subjects with discomfort won't be discouraged from engaging with the experiment.

3.2.2 **User Interface Design**

While there has been a lot of research into different types of new user interactions, an overall standard for VR has yet to emerge. This is, in part, owed to the high speed of new technological advancements in this field, often leaving technological documentation dated or even obsolete soon after it was published. This trend, however, is likely to change in the coming years, as the major brands of VR headsets, like Oculus, Steam and HTC, are starting to converge on what may soon be a standard for the high-end devices. Almost all current devices are equipped with the same basic components, such as:

- 6DoF headsets
- Controllers, each with one joystick and several additional buttons

Emerging platform independent APIs and game engines, such as SteamVR, Unity3D and Unreal Engine, supporting most current headsets will likely lead to a state similar to that of current video-game consoles. Each brand will bring their own specific features, advantages, and disadvantages, yet software engineers and designers will still be able to rely on certain functionalities to be provided by default.

Creating user interfaces, both graphical and non-graphical, obviously comes with new challenges when creating a VR application. Aside from the obvious tasks that exist in 2D desktop software, like selecting options and triggering events by pushing buttons, VR introduces a new mechanic:

3.2.2.1 Movement

Giving movement commands is nothing new for those accustomed to video games or non-VR 3D simulations. Gaming consoles rely on joystick input (generally one joystick for movement, one joystick for looking around) and 3D desktop applications rely on keyboard commands (arrows keys or WASD[3] for moving forward, backward, left and right) coupled with mouse motion to look around. Looking around is obviously solved in current VR headsets, as the heads rotation directly controls the virtual camera rotation, but movement is a trickier problem. Most current VR headsets track rotation as well as movement to a certain degree, meaning within a limited space users can move their heads and even walk around freely, with their motion directly translating into the motion of the virtual camera[4]. The problems begin as soon as users walk into objects or walls in their physical environment or want to move through the virtual world while sitting in the physical world. In these cases, application designers generally have two choices. They either use a teleport-function, in which the user points to a specific position and presses a

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[3] The W, A, S and D keys are used just like arrow-keys, but on the left side of the keyboard.
[4] Unless the simulation deliberately ignores headset movement to fix the user in one place.

button that triggers the camera to jump to that point instantly, or they use joysticks. The advantage of teleportation is the ability to travel large distances in an instant and ease-of-use, since those unfamiliar with joystick controls will likely struggle to move in the beginning. While the sudden change of view might be a little jarring, it will likely not cause the same level of sensory irritation that users might experience when moving with joystick controls, since the visuals tell their brains that they are moving, while their sense of balance tells them the opposite. Joystick movement on the other hand is more immersive, as most people do not get to teleport in real life. It is also more convenient when moving very short distances, like a single step, than having to point down and click every time one wants to move forward or slightly to the side.

3.2.2.2 Object Manipulation

The premise of this experiment is that subjects can spatially arrange memories of various media types, as well as optionally decorate "memory-rooms" (one room representing one day) to give those memories a context. One straightforward way of solving the issue of object manipulation is implementing a user interface just like in a 2D desktop environment. While this obviously does not take advantage of the potential of VR, it does come with a couple of advantages over an innovative 3D interface. One advantage is simplicity. When touchscreens became mainstream through smartphones, most people did not struggle learning how to activate buttons, select options from lists or drag pictures across the screen. If such a UI were to be implemented in VR, most people can be expected to grasp it relatively quickly.

In terms of ease of use, 3D interfaces are a double-edged sword. On one hand, and depending on the type of interaction, they may be less familiar, unless they very precisely emulate the physical world. On the other hand, in those cases of real-world emulation, they can become a Natural User Interface (NUI), an interface so familiar, that it does not require conscious thought to be used (Kharoub, Lataifeh, & Naveed, 2019). An example of this would be the picking up of objects by touching them with a controller, which is either visualized as itself or as a hand. Such an interaction would also reach a very high level of immersion. 3D interactions are also generally more flexible and experienced as fun (Saffer, 2008).

One disadvantage that might lose its relevancy in the near future is that current VR headsets have different sets of features, requiring a UI implementation to either be re-implemented for different devices, or focus on a single device.

An interesting observation made by Bowman et al. (2006) that still largely applies today, is that most applications for VR that favour or entirely rely on 3D interfaces only have very simple interactions. Devices such as the Microsoft Kinect or Leap Motion, which monitor body parts such as arms or legs, also have not found widespread use. This is owed to the fact that using elaborate gestures, while technologically impressive and entertaining, is often laborious and difficult to get right, or, for the lack of a better word, "fiddly". What such fiddly user controls look and feel like was comedically, yet

accurately expressed in the comedy sketch "What Minority Report Computers Would Really Be Like", in which a futuristic holographic gesture interface leads to chaos and confusion in an office environment (Schaubach, Marovitch, & Crown, 2017). Bowman et al. (2006) did however conclude that, while 2D controls are more attractive to new users in the beginning, overall, more natural interactions are preferred.

In a more detailed comparison, a 2D, a 3D and a speech interface (triggered by voice commands) were put to a test, in which subjects were tasked to select and place a piece of furniture. The interfaces were compared in the following categories.

- **Usability**

  In terms of usability there was not a clear winner, but each interface got the job done.

- **Ease of learning**

  The 3D interface lost to the other two, which can be explained by the fact that most people are familiar with desktop interfaces and voice-controlled digital assistants.

- **Clarity and comprehensible representation of data**

  2D interfaces outperform the others, as the mere sight of them is usually enough to instantly understand their mechanics and purposes. For example, when presented with a slider, a user will immediately know that they are supposed to control a value within a certain range of options, most likely on an ordinal-, interval- or ratio scale. Speech interfaces did substantially worse than the other two, as possible commands or options are generally unknown to the user until they tried them.

- **Efficiency**

  2D placed first, 3D second and speech third, since it takes significantly longer to utter a sentence than to touch an object or click on a button.

- **Immersion**

  2D was outperformed by 3D and speech interfaces.

- **General satisfaction**

  Despite its otherwise good performance, 2D interfaces fared the worst in this category. This might be because it is the one most alike to mundane desk work, or simply because it is the least immersive.

In conclusion, 2D interfaces generally perform best in terms of productivity and worst in terms of satisfaction, while speech- and 3D interfaces are more fun to use, with 3D however clearly outperforming speech interfaces in terms of efficiency. It will be up to interface designers to decide what prioritize. In this case, both efficiency and immersion are of high importance. Subjects should feel satisfied as they creatively express their moods and memories, however, since they are tasked to do that for up to a week, it is also important not to demand too much effort. Therefore, where possible, 3D interactions were

implemented for the most common and simple tasks, such as placing, picking up and moving objects, while a 2D UI was used for data representation and manipulation.

Speech interactions will not be implemented since they performed the worst overall in the above comparison. Their use is too slow since each word or sentence first has to be processed and (if possible) mapped to a predefined command. There is also a higher chance of failing to recognize the command. Not much confusion can arise when pressing a button, however if a user says "reposition" instead of "move" or "no, wait, that's not what I meant, damnit!" instead of "cancel", the software might not be able to correctly map the command. There is also the issue of privacy, since state of the art voice recognition uses cloud computing, meaning voice inputs would be uploaded to a server. This will likely change in the near future when offline speech recognition will mature on android devices. Most importantly however, it would be very difficult to communicate which commands or options even exist without putting the user through an extra tutorial, requiring them to remember precise commands. It is important to note that speech interactions do have potential but are not readily available and feasible for this experiment setup. Furthermore, speech interfaces do have one important advantage over 3D interactions in VR:

3.2.2.3   Text Input

Currently, if not dictating, text input in VR is done through a virtual keyboard. While this may at first sound like a simple and adequate solution, it turned out in practise to be slow and tedious. Since VR controllers represent entire hands, rather than everything down to the individual sections of a finger, typing requires the user to move their entire hand and press a button for each character. Dictating is likely the better option in this field, but it would need to be an optional choice in this case, since, due to the private nature of diaries, every feature that requires an internet connection and server-client communication will be made optional.

Chapter 4: Implementation

Three software implementations were required to record and transmit data from the user's phone to the headset, process it and display it within the 3D diary. Not only the research itself, but also the software architecture required are experimental, and so it was not clear before months into the implementation process that the experiment could actually be conducted. The implementation itself, from the first design draft to a complete working system, took eight months. Both software and available hardware still have significant drawbacks, which limited the user experience and are relevant regarding the interpretation of findings, as well as future opportunities and possible improvements. This chapter gives a broad overview of the software systems in use, as well as insight into each of their inner workings.

4.1   Introduction

Figure 10 provides a high-level overview of how three major pieces of software interlock to provide a data pipeline from the user's mobile phone to the headset.

1.   Companion App
The mobile *Companion App* is used to capture and send memories to the headset via Wi-Fi.

2.   Quest Companion
Running as a background service on the VR headset, the *Quest Companion* receives and processes memory files, making them available to the VR diary.

3.   VR Diary
The VR Diary, called *Memory Mansion*, provides the interface, and allows the user to creatively arrange and decorate the memory rooms.

Figure 10: Data pipeline from the mobile app to the backend and visualization on the VR headset

To conserve time and effort, the mobile *Companion App* was limited to Android devices, but the same principle can be applied to iOS devices or PCs. The decision to transmit files directly via Wi-Fi, and not over the internet, was made to prevent privacy issues, especially to get the greenlight from the university's ethics committee. In a commercial product, in terms of pure user experience, a dedicated server to handle both

transmission to the headset and memory processing, would be the better choice (see 7.3 for details).

Since the Oculus Quest headset uses a heavily modified Android operating system, the background service in charge of receiving and processing memory files was written as an Android application as well. The VR application is accessible as *Memory Mansion* in the headset application menu.

4.2   Mobile Companion App

The mobile app was built on top of the P2P-File-Sharing app (Tambapps, 2020). Even though a lot of functionality was added, like the taking of photos, videos, voice recordings, text notes and the automatic compression and encryption of transmissions, it was kept very simple to avoid any kind of hassle for the subject while making recordings. The main screen (see Figure 11, top left) shows files queued for sending and provides buttons to search and include files, as well as capture photos, videos, take voice recordings and text notes. It is the only standalone screen in the entire app. Every other screen is part of a simple step-by-step process, started on the main screen. At the first start-up, a random security code is generated (see Figure 11, top right) for the user to manually input into the Quest Companion on the headset. That code is used to encrypt memory files on the phone and decrypt them on the headset. Whenever the transmission list is not empty and the headset is found over Wi-Fi, all queued files are packaged into an encrypted zip archive. That way, only a single transmission of one (relatively) large file is required, which is a much faster method than encrypting and transmitting each file individually. In most cases the pairing of the headset and mobile phone takes up most of the time of the transmission process, except for cases in which very large files (such as long HD videos) are transmitted. Furthermore, this allows the easy bundling of the actual media and meta-files, which contain information like the user-given title, description, rating, or tags (see Figure 11, bottom right). The settings-page (see Figure 11, bottom left) allows the user to change their language, as well as privacy settings.

Memory files transmitted to the headset are not sent via the internet, as that would require a well secured data server, immense trust from the users and would likely not be approved by the ethics committee. Instead, the subject's private Wi-Fi is used. That way, their memory files are never in the researcher's possession, avoiding the question of trust and the high effort of building a secure online data pipeline. The only way for a third party to gain access to the memory files is to either steal the headset itself or break into the subject's Wi-Fi and then also break the password encryption. Since the encryption key is never transmitted, but manually input by the user, it can also not be stolen without access to the hardware. The options to use the cloud voice transcription and text sentiment analysis on memory files are disabled by default, to ensure user data is only ever (temporarily) uploaded when explicitly requested by the subject.
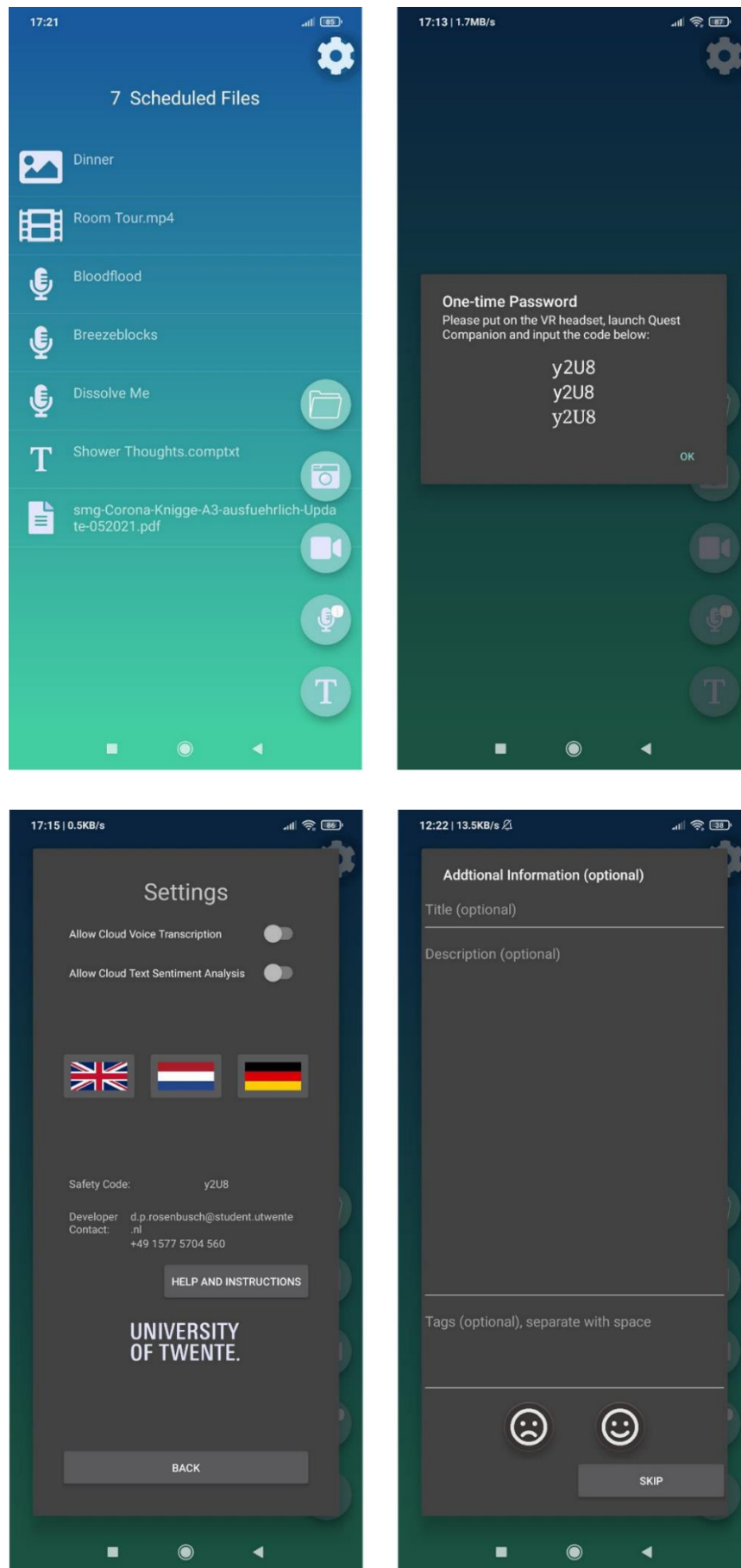
Figure 11: All screens of the mobile app (top left: Main Screen, top right: password for data encryption, bottom left: App Settings, bottom right: Annotating Memories

4.3 Quest Companion Backend

The Quest Companion is built from the same technology stack as the companion app. Gray-coloured in Figure 10, the Quest Companion is not meant to be interfaced with by the user, aside from the setup. Instead, it runs continuously in the background, receiving and processing files.

4.3.1 Data Processing & Analysis

Once received on the headset, the zip archive is decrypted and the media- and their respective meta-files are stored in a directory with regards to the current date. The metadata is then stored in a SQLite database to allow fast access without traversing directories. The date, time, and title within the meta-entries is sufficient to locate the media-file of every entry. An SQLite database is a popular solution for local databases on Android devices, as it is a single-file database that does not require an installation, configuration and is open source. Once stored and registered, the media-files themselves are processed and analysed.

Any received audio recordings that were made with the Companion App's speech recording function are converted from raw PCM (Pulse-code modulation) to MP3 files using the Ffmpeg (Fast Forward MPEG) library. MP3 files, unlike raw PCM, can be played from within the VR diary, as the game engine does not recognize the latter. The uncompressed PCM is kept for later analysis.

The analysis is concerned with the question of whether a memory is rather positive, neutral, or negative. Should the user have enabled it, a cloud-based sentiment analysis is performed on any piece of text, whether it is a full text-note or any metadata, such as titles, descriptions, and tags. The cloud analysis is performed using Google's Cloud Natural Language API, which returns a numerical sentiment evaluation of a piece of text. Should the user not have enabled this feature (as it is disabled by default), a rather primitive offline analysis is performed. Self-hosted solutions for natural language processing do exist, however, they are generally meant to be run by a server and not a mobile phone operating system such as Android. The only library compatible with the headset that was found is OpenNLP, however it performed very poorly (i.e., slowly) and regularly crashed with out-of-memory errors. For that reason, a primitive, yet for simple tasks, sufficiently accurate method was employed that searches texts for negative and positive words. This approach however can obviously not handle any kind of nuance, negations, or sarcasm. Furthermore, a search for common German, Dutch and English names is conducted throughout all pieces of text. When a name is found, it is automatically turned into a tag. Those automatically generated tags, as well as manual tags (see Figure 11, bottom right) are used to find connections between different memories.

Any speech recordings are, should the user have enabled this function, transcribed into plain text via Google's Cloud Speech-to-Text API. This can be useful to review a

recording faster than listening to. Furthermore, it allows the transcribed text also to be analysed as described above.

4.3.2 **Metadata Extraction**

While the actual memories are not inspected by the researcher, the metadata of the VR Diary usage is extracted at the end of each testing period. For that purpose, the subject can go into the Quest Companion App and activate the metadata extraction if they are willing. The metadata extraction reads metadata from the database and the created rooms themselves and turns them into a JSON document, which is displayed to the subject, so they can see their privacy is respected, as all plaintext is hashed. Should the subject feel that their privacy is not violated by this data, they can select "send" to have it sent to the researcher's email-account. Thereafter the subject can export all their private data as a zip archive to transfer it to their private computer. They can also select "Delete Data" to remove all their private data from the headset before returning it.

4.4 **VR App**

The VR diary app is the visual interface to all recorded memories and memory rooms. It needs to read memories (photos, videos, music, etc.) from the headset's file storage and metadata from the SQLite database. The media and metadata then need to be visualized as part of a 3D room (per day). The user needs to have simple tools to spatially adjust and search these memories. Furthermore, the user needs to have tools to adjust the style of each memory room through settings such as colours, lights, windows, and inserting furniture and decorative objects. The users are expected to have little to no experience with virtual reality, meaning these tools need to be accessible and encourage experimentation.

This section will elaborate on the technology stack chosen, technical- and design challenges and interaction design.

4.4.1 **Engine**

There are several free-to-use and VR compatible 3D engines, most notably the Unreal Engine, Stride Engine and Unity3D. Unreal Engine, the oldest and most advanced option, provides the best graphical quality out of the box, it does however come with a steep
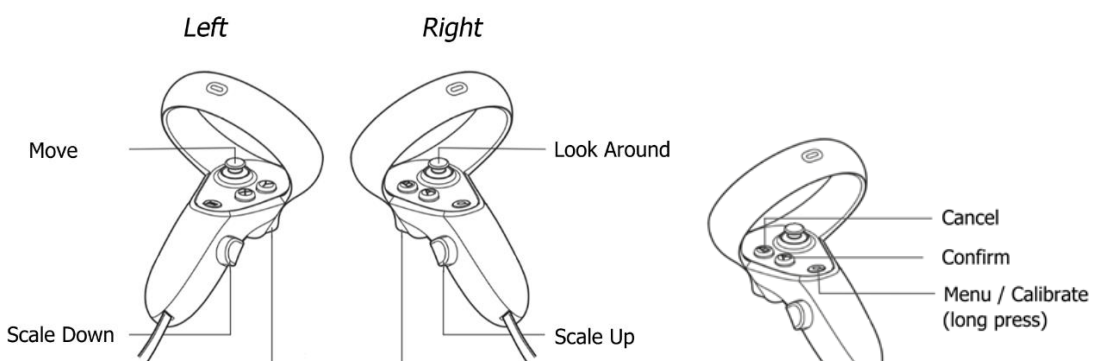
Figure 12: VR Diary Controls

learning curve. The Stride Engine is the most recently developed option, easy to learn, but still quite unstable and has a comparatively small community for support. Unity3D is as easy to learn but has been around since 2005. Due to its usability, it has garnered the largest community of the three, with a large asset store that offers many free-to-use modules and models. While not the most modern or visually impressive solution, Unity3D was chosen for ease of development.

4.4.2 UX Design
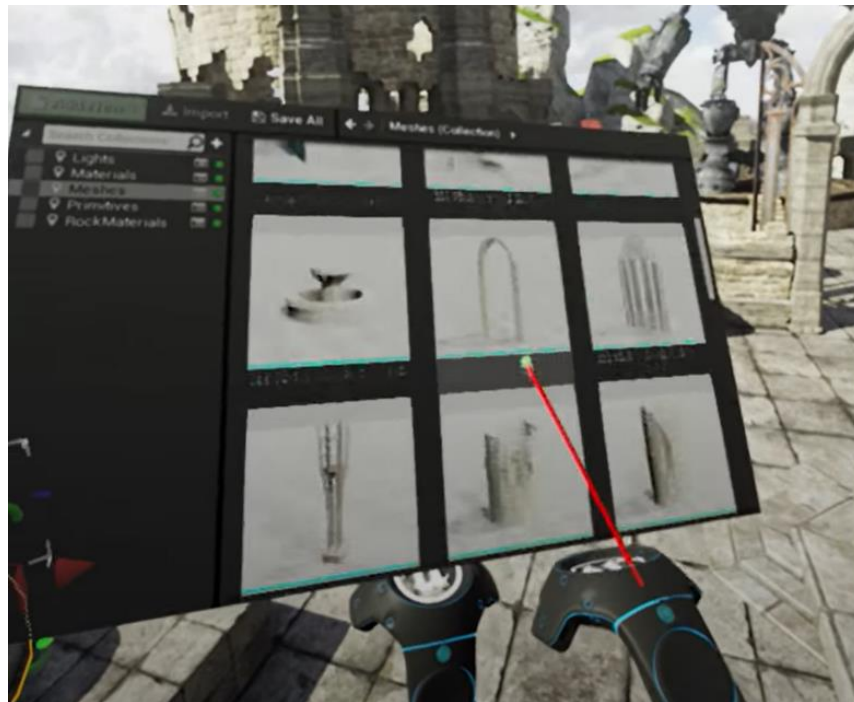
Figure 13: Unreal Engine 4 VR Editor (Epic Games, 2021)

The VR application places the user in a blank, empty room with two doors, which automatically swing open when the user nears them. The room itself represents a single day. One of the exits leads to the next, one leads to the previous day. The user can move either using the joysticks or through physical movement, tracked by the headset. Since
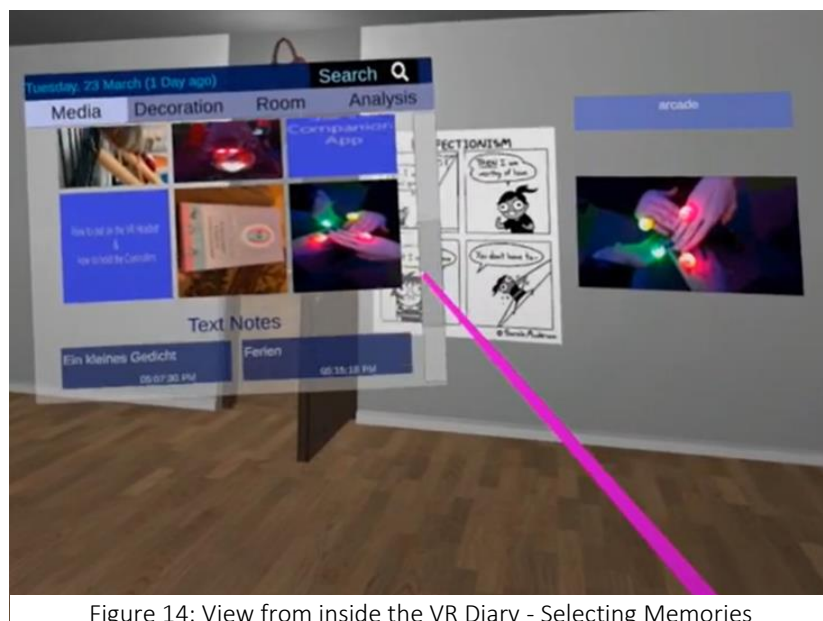
Figure 14: View from inside the VR Diary - Selecting Memories

this experiment played out in a single room at a time, in which only short distances must be travelled and immersion is of a high priority, joystick controls were favoured over teleportation.

The user's right hand has a visible ray attached to it, like a pointing stick, and is used to select and manipulate objects. Stuck on the left hand is a tablet-like UI panel, displaying
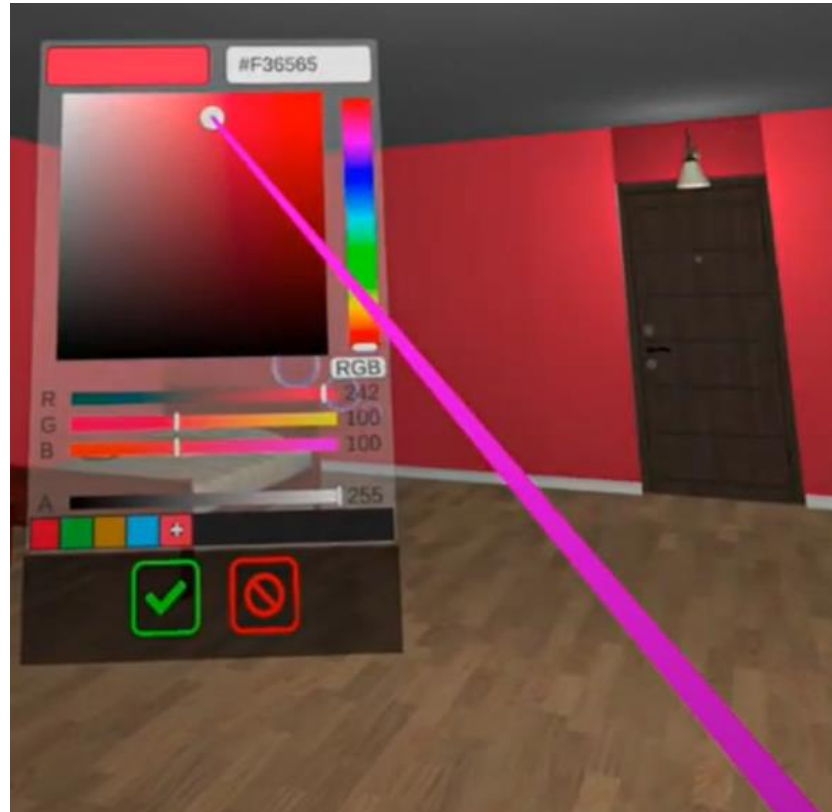
Figure 15: View from inside the VR Diary - Adjusting Room Colours

the memory objects of the current day (see Figure 14), and room settings. The UI, like the 3D world, is controlled using the right hand. This design is in line with common editor-like VR UIs, like in the Unreal Engine VR Editor (see Figure 13) and Munx-VR (see Figure 8). Should the user be in the room of the current date, then the door leading to the next day is locked. Past days' rooms can be visited, but no longer changed, to prevent users from altering or rearranging their memories, to avoid information distortion and decay. Aside from placing memories, users can also place a range of 3D models, such as furniture, pets, plants, books, and other common interior. They can also change the visual appearance of each room to reflect their mood. They can control ceiling height, window placement and scenery, light conditions, the material of the floor, ceiling, and walls (wood, stone, tiles, etc.) as well as their colours (see Figure 15).

When selecting a memory object or 3D model within the room, an additional UI panel pops up, displaying information such as the object's name, description, mood rating or any user-given tags. It also exposes controls to move, scale, rotate or remove the object, as well as media-specific controls, like for audio- or video playback, as seen in Figure 16.

Based on user satisfaction and productivity benchmarks (refer to Section 3.2.2.2), the placement of objects was implemented to be as natural as possible, using 3D controls. To

Figure 16: View from inside the VR Diary - Music Playback

place an object, the user selects it, after which it snaps to their hand, as if they are holding it. Thereafter, by pressing the Confirm-Button (see Figure 12) on their controller, the user could place that object. While more natural, more elaborate gesture controls for object manipulation or data alteration were avoided and instead implemented as a 2D UI floating in 3D space.
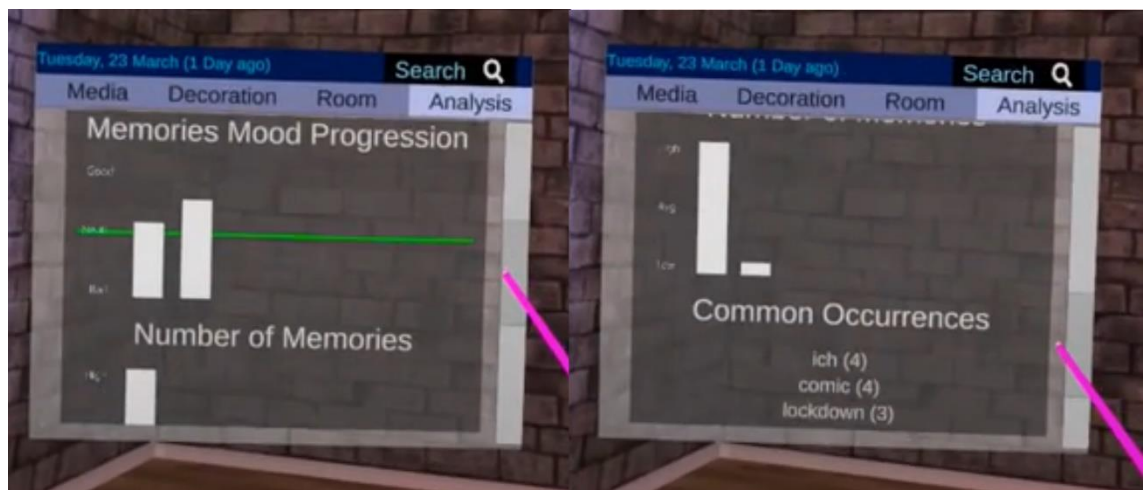
Figure 17: View from inside the VR Diary - Analysis Tab

A rudimentary content analysis is performed during runtime and results are displayed in the "Analysis Tab" of the VR tablet. It shows information such as mood progression, number of memories by day and frequently occuring words. Selecting one of these words
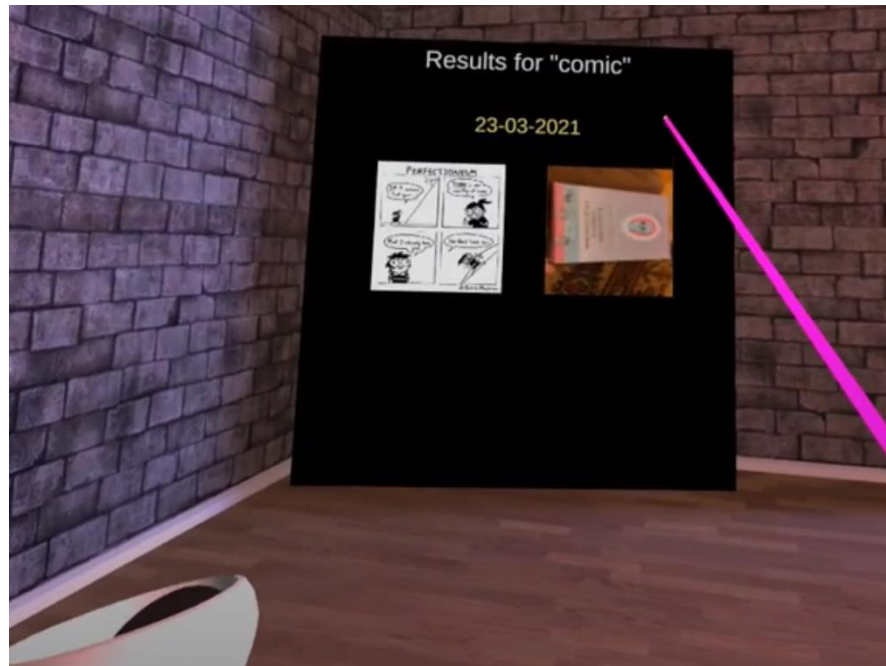
Figure 18: View from inside the VR Diary - Fulltext Search

automatically loads a list of the media containing them. Manual searches for any word can also be performed (see Figure 18).

4.4.3 Hardware Requirements and Performance

Since the internals of the Oculus Quest 2 headset resemble a VR optimized Android phone that has to be light enough to be worn on the user's head, its hardware capabilities are rather limited. For that reason (and lack of budget), the environments are simplistic. For the VR diary this means that displaying multiple high-resolution photos or videos at the same time in a VR space with multiple, potentially animated, models (such as pets), requires measures to limit memory- and processing demand. The limiting of processing demand was addressed by lowering the lighting quality of the simulation, avoiding casting multiple lights, realistic shadows, downscaling textures and using 3D models with low polygon counts.

As for the memory demand, while the Quest 2 has 6 Gigabyte of RAM in theory, available to the simulation are only around 1.7 Gigabyte. This was shown by gradually loading more and more photos inside of a room, until the application would crash, which regularly occurred at the 1.7 GB mark. For that reason, visual media is downscaled significantly. When a 4k photo is sent to the headset, copies of lower resolutions are generated. For instance, the media browser (see Figure 14), only shows a low-resolution thumbnail of each photo, thus not requiring a high-resolution rendering. The maximum resolution rendered in the simulation is kept lower than or equal to the native resolution of the

headset screen, as no visible difference occurs that way. This method was vital to allow users to place dozens of photographs in a single room.

Another measure put in place to enhance performance and lower memory demand was unloading rooms outside of the user's view. As the user can only ever see two rooms at the same time (when looking through a door from one day into another), the rooms directly before and after the current room are always loaded in memory. As seen in Figure 19, rooms that can not be immediately seen by the user, are automatically unloaded, while rooms that come into range of possible sight (if a door opens as the user approaches it) are automatically loaded.
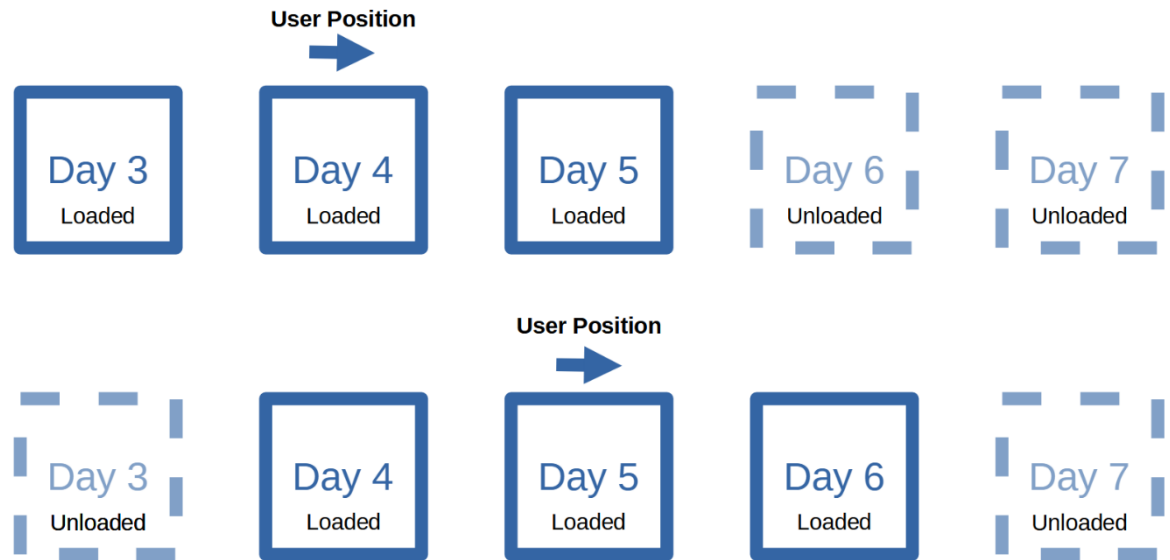
Figure 19: Loading and unloading memory rooms as the user moves from day to day

This procedure does not only conserve memory, but also allows for memory objects to be asynchronously loaded one at a time. If only the current room was loaded into memory and the next room, as the user approaches, had to be loaded instantly, all memory objects, which could be dozens of photos, videos, and 3D models, would need to be loaded simultaneously. This would lead to the simulation to halt for several seconds, making the transition from one day to the other rather tedious. Since with this approach the simulation has enough time to load and unload days one memory at a time in the background as the user traverses the rooms, they are never aware of rooms disappearing behind and appearing in front of them.

To conclude, while the current mobile VR hardware can not deliver high-end graphics, it can, if used correctly, deliver a seemingly endless corridor of memory rooms, equipped all kinds of digital media.

4.5 Conclusion

While functional, the implementation of the VR diary is narrow in terms of platform compatibility, on the low end of graphical quality and, due to being a one-man project, rather unstable. Multiple bugs were found during testing, negatively impacting user

experience, yet not severe enough to invalidate the tests. This version should not be used in future research but can act as a starting point to be improved upon.

Chapter 5: Methodology

This chapter explains the practicalities, planning and steps of the experiment. The first two sections explain restrictions of the data collection due to privacy concerns and a hypothetical playthrough of the experiment to assess subjects' wishes and reservations. These steps were important to guide the experiment design, which is discussed in the third section. The fourth section elaborates on the applied measures, with the fifth explaining how these measures will be used to answer the research question.

5.1 Privacy

This project, as it handles intimate private data in an unsupervised setting, needed to treat the participants' privacy with great care. This is not only important from a moral, but also practical standpoint. Should participants be unsure if their privacy was respected, they might censor themselves in their expression, if they assumed to be judged for their memories in the aftermath. This concern is backed up by the Hawthorne effect, which, although controversial for being used too broadly, suggests participants in studies alter their behaviour when knowing they are being watched (McCambridge, Witton, & Elbourne, 2014). This would distort the outcome, both in terms of metadata, as their use of the VR diary might differ, and interview results, as they are likely not going to get the most out of the diary. It is important to note, however, that there is a conflict between extracting as much data as possible for analysis and extracting as little as necessary to not invalidate the data for the above reasons. A balance needed to be found between quantity and quality.

The following compromise was made:

- No content of any memories is ever seen by the researcher, unless voluntarily shown by the participant.
- No content of any memories ever finds its way to the internet, unless explicitly wished for by the participant, to perform advanced sentiment analysis using Google Services.
- Exact usage time (of the day) is not monitored

This compromise allows gathering metadata on the app usage, such as media types and occurrences of keywords (although hashed to preserve privacy), while not disclosing any media content.

5.2 Preliminary Test

As soon as the feasibility of the software was ensured with a proof of concept, a first test, followed by a series of interviews with prospective test subjects, was conducted. Being an exploratory experiment, it was important to narrow down the range of required and nice-to-have features and steer the general direction of development. During this preliminary test, eight subjects were asked to spend a few minutes each day to gather

important memories in the shape of photos, videos, voice recordings, texts, physical writings, or other types of media. After 4-7 days (depending on the subject), there was an informal interview via video call with the subject about their experience, ideas and wishes for a virtual diary in which they could put these memories. The interviews were kept in a casual manner, where specific questions were asked, but for the most part the subjects could steer the conversation to get an idea of their recording habits, media preferences, feature requests and reservations, as well as their willingness to invest effort into such an activity. The subjects ranged from 21 to 60 in terms of age, with an average of 34 years.

The interviews showed a great variety of preferences in terms of usability, privacy concerns and potential use cases. Subjects will likely not create a new memory room every day, as some days are either too stressful, too uneventful or subjects simply forget. Subjects also noted that current days do not represent what they consider to be their normally scheduled life due to lockdown and worries about COVID infections, as they are living through a pandemic. This will need to be considered when analysing their software usage. For instance, since people are not meeting as much as usual, it was deemed not worth the effort implementing facial recognition for recorded photos or videos. In terms of time commitment, subjects spent about 10 minutes a day on average creating memory files. The most popular types of media are the following, ordered by popularity:

1. Pictures (leading with a wide margin)
2. Videos
3. Voice notes or voice messages
4. Text notes / text messages
5. Songs
6. PDF documents
7. Websites
8. Search histories

This will play a major role when deciding which types of media the VR software will need to be compatible with. As for text specifically, there will most likely be subjects not willing to type on their phones at all. They will need to be accommodated, for instance by assigning automatically generated titles for recordings or making annotations optional. Every participant stated that they would use their smartphone for making recordings, although PCs may additionally be used. As for the amount and size of the files, none of the participants would have come close to the storage limit of the Oculus Quest 2 device, meaning that during implementation the focus should lie on memory efficiency during runtime, relating to the RAM, rather than optimizing storage space. Generally, there is interest both in doing these kinds of recordings over a longer period of time and looking back on recordings further in the past. People recorded both everyday things of minor importance and major life events, such as birthdays. In terms of scheduling, some are triggered by certain events to start recording, while others do it regularly as a ritual. Furthermore, some people would like to be prompted by the app to note their thoughts

and feelings, while others find prompts are intrusive and annoying. As this is a rather short test, it was decided not to prompt subjects, but rather observe how often they think to use the VR diary on their own.

For the complete interview protocols, refer to Appendix A.

5.3   Testing

Since diaries are generally used over longer periods of time, a single test-run could not be executed during a single day. Rather, this is a diary-study-esque design following the interval-contingent testing, described by Bolger, David & Radaeli (2003). While a longer test-run was more likely to give new insights and more valuable feedback, it would also have decreased the sample size and put a higher burden on participants, perhaps to the point of them deciding not to participate. A compromise had thus to be found, and it was decided to aim for at least four days of use per subject, with a maximum of seven days, depending on their schedules. Skipping uneventful or overly stressful days was, as is with conventional diaries, acceptable.

5.3.1   **Finding Participants**

Achieving a large enough sample size was a major challenge for this test for several reasons. The three most substantial limiting factors were the number of available VR headsets, the overall length of the experiment and timespan of each individual test. Adding more time to the length of the experiment would have diminished the time for development, bug fixing and subsequent analysis. It was thus limited to three months, which already resulted in significant stress and strain to finish the software on time and finish the analysis soon after the tests ended.

The number of headsets was limited to three in the beginning, two coming from the HMI lab of the university, one from the researcher. Later, during testing, a fourth headset was borrowed from a relative, as the schedule started to develop a bottleneck due to transport issues.

The timespan for each test was set to one week, this was however flexible, since participants occasionally had to end earlier due to their own scheduling. This would, in theory, allow for four tests per headset per month.

Naively, this would result in a sample size of

$$3 \ months * 3 \ headsets * 4 \ tests \ per \ headset \ per \ month = \ 36$$

However, since the tests were executed in participants' homes, meaning they were given the equipment and agreed to return them, not anyone willing could be deemed suitable for participation. With only three headsets being available in the beginning and the cost of each headset falling between 400 € and 500 €, it was decided to limit participants to a pool of people that were trusted by the researcher. That pool included friends, friends'

families, extended family, fellow students, and other acquaintances with some accountability.

Among those deemed trustworthy, it became a challenge to find enough that were willing to spend multiple days collecting memories and familiarizing themselves with the VR headsets, all at a slightly increased risk of infection due to the COVID pandemic and without financial remuneration, as this research is not being funded. To create excitement and recruit participants for the experiment, an advertisement video was created showcasing the possibilities of a VR diary.

Video Ad on YouTube

Only very few participants were found that lived close to the researcher, meaning the headsets had to be delivered or sent via mail, adding additional time and expenses. In the worst cases, a headset would take up to ten days to be delivered to the subjects, when it had to cross the border between Germany and the Netherlands, and another ten days to be returned, lowering the number of subjects for that month to one for that headset. However, even in the most optimal cases, where theoretically a headset could have been passed on from subject to subject on the same day, an additional time gap was introduced as a safety measure due to the COVID pandemic.

In conclusion, due to the lack of devices, strict time constraints, high time demands, heavy burden on participants and the ongoing pandemic, only a sample size of 18 was achieved.

5.3.2 COVID-proof testing

There is no way of creating a COVID-proof test. Participants were, through the nature of the test, at a higher risk of infection, since they had to use equipment prepared by the researcher. The researcher, in turn, was at a higher risk as well since they had to retrieve and clean the used equipment. The best that could be done was to reduce the risk as much as possible and inform participants about the remaining risk. Participants were asked to reach out, should an infection be found before, during or up until two weeks after the testing period, to prevent a possible chain of infections.

Before and after each test, the headset and controllers were thoroughly cleaned with 75% alcoholic wipes, except for the lenses, which would run the risk of being damaged. The lenses were instead wiped with microfiber cloths. Furthermore, the facial covers were exchanged between participants, giving each facial cover at least one extra week after the disinfection for any potential virus to disappear. Lastly, the same headset (and controllers) would never be used by more than one participant in the span of three days, giving the potential virus additional time to disappear. The researcher also regularly tested themselves for antigens, as did many of the participants before the test.

The procedure adheres to the universities safety policy and was, between the researcher, first supervisor, ethics committee, and university laboratory staff, deemed sufficient to provide enough safety. As of the time of this writing, no participants have been infected with the virus.

5.3.3 **Testing Procedure**

| Mobile App Tutorial | VR Headset Tutorial | VR Diary Tutorial |

After agreeing on a timeframe for the test-run, a VR headset was prepared (i.e. cleaned and given a fresh install of the required software) and either sent via mail or hand-delivered. When the subject did not possess an Android phone, they were given one to run the mobile app. The subject was shown a series of short tutorial videos concerning the VR headset, the mobile companion app, and the VR diary software. These videos are also automatically placed in the "Lobby"-room in the VR diary. Both the companion app and VR diary provide links to a help-page that answers frequent questions and provides further short explanatory videos[5]. After the initial setup, the first of two questionnaires was filled out to provide some general personal information (refer to section 5.4.1.1) and the first reading of SRIS values.

During the following 4-7 days, the subjects used the VR diary app at their own discretion and without supervision, although the researcher was always available via phone or email to answer any questions. After the usage phase, the second questionnaire was filled out, documenting the subject's experience, and giving a second SRIS reading. Using the headset, the subjects extracted the usage metadata and were given a chance to review it to assure their privacy was respected. Subjects were also shown a button to remove their memory data from the headset. The equipment was either returned via mail or picked up by the researcher.

5.4 **Measures**

As this is an exploratory experiment, the primary measure is whether subjects gain value from using a VR diary, also in comparison to conventional diaries. Should generated value be found, its nature would be of interest as well. These subjective experience reports come from the prior- and post testing questionnaires, and through engagement analysis through metadata. Secondary measures are changes of SRIS values and use (or omission) of specific features to learn about opportunities for improvements and refinements.

5.4.1 **Engagement**

Value through engagement was primarily measured through direct feedback in the interviews. Engagement itself was also measured through metadata analysis of the app usage. The resulting qualitative and quantitative data was cross-referenced, for instance

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[5] The help-page can be found in German and English language at https://therdavid.github.io/Memory-Mansion-VR-Landing-Site/

to find correlations between age and usability issues or whether or not they were journal keepers and liked or disliked the VR diary.

5.4.1.1 Interviews

The following data was gathered through the interviews:

Questionnaire Prior Testing

- Name, Age, Gender, Nationality
- Journal Keeper (Yes, No, In the past but not now)
    - If any other answer than *yes*, then why not (anymore)?
- Has used a VR headset before
    - If *yes*, then for what purpose?
- Has played video games before (Never, Rarely / A long time ago, Occasionally or Frequently)
    - If *yes*, then what kind (examples)?

Questionnaire Post Testing

- What did you like / dislike about the experience of the VR diary?
- If you have previously used a conventional diary: How does the VR diary compare?
- Which aspects of the VR interface were difficult or uncomfortable?
- Did you find any interest or use in the automatic analysis (elaborate)?
- How long (roughly) did you use the VR app each day? Did it vary between days?
- If you owned a VR headset, would you be inclined to use such an application long-term?

The gathered data gave insight into common issues with VR interfaces and which groups of people struggle with them the most, regarding their age and prior experience with VR and video games. The expectation was that with lower age, generally, comes a quicker adaptability to new technology, while a background in video games will likely show a less steep learning curve due to known concepts such as virtual worlds, interactive simulations, and joystick controls. This data is relevant to assess any new-found value in the VR diary (or lack thereof).

5.4.1.2 Metadata

The usage data of the VR app revealed preferences, use (or omission) of certain features and general activity, like the number of memory objects placed per day. This data was relevant to determine which activities or features create more (or less) value and engagement. The full list of metadata is as follows:

- Daily mood and in-app-experience (Likert values 1-5)
- Used Google Services for Speech-To-Text
- Used Google Services for advanced sentiment analysis

- Memory Objects
  - Names (hashed)
  - File paths (hashed)
  - Description lengths (not the descriptions themselves)
  - Date
  - Media Type
- Tags
  - Name (hashed)
  - Automatically generated or user-created
  - Related Memory Objects

This data was relevant to determine which activities or features create more (or less) engagement and are thus creating value for the user and useful tools to motivate participants during future research.

5.4.2 SRIS Changes

There is no general set of value ranges for SRIS-SR or SRIS-IN to evaluate an individual's level of self-reflection or insight. However, since the SRIS scale produces values on the interval scale, they can be compared between subjects, and, in this case more importantly, within the same person at different times. When establishing the self-reflection and insight scale, Grant et al. provided factor loadings for self-reflection and self insight for each item on the SRIS questionnaire from two different studies. The average of these loadings was used to weigh the subjects' answers, with some of the answer-scores being reversed prior (refer to Table 2).

It bears mentioning that the circumstances of the test are not optimal to spot differences in SRIS readings. Changes in SRIS values are not a given, even with a more impactful diary alternative. Furthermore, a longer testing period would be more likely to yield statistically relevant results, however, as discussed in section 5.3.1, the timeframe for each individual test was limited to achieve a higher sample size.

5.5 Analysis

Once the testing procedure was approved by the ethics committee, the analysis of the to-be gathered data was planned. As this is a mixed-method study, the analysis attempted to find general themes within the data, backed by the quantitative and qualitative findings. For that purpose, answers to open-ended questions by subjects were coded. Where possible, these codes are connected to existing or missing features in the VR diary. This results in recommendations and guidelines as to how the implementation may be improved to increase engagement and address issues and complaints by the subjects. Since this first implementation has a broad range of features to capture as many themes as possible, it may also aid in altering future versions to focus on individual use cases or more narrow goals in future research.

Chapter 6: Findings

The research question (How to design a VR diary that allows people to generate value for themselves?) can be answered positively if there is evidence of a new kind of value created using the VR diary, for instance through found themes that are not encountered in traditional diaries. Furthermore, looking at the kinds of value created and the possible directions for future, less exploratory research, focusing on specific aspects and user experiences, can be conducted with this thesis acting as a base.

Questionnaire Item	Study 1		Study 2	
	SR	IN	SR	IN
I don't often thing about my thoughts (R)	.68	-.01	.32	-.07
I rarely spend time in self-reflection (R)	.78	-.02	.61	-.12
I frequently examine my feelings	.86	-.07	.85	-.09
I don't really think about why I behave the way that I do (R)	.72	.10	.57	-.02
I frequently take time to reflect on my thoughts	.72	.01	.77	.04
I often think about the way I feel about things	.72	-.08	.72	-.02
I am not really interested in analysing my behaviour (R)	.71	.02	.63	-.05
It is important for me to evaluate the things I do	.75	.00	.76	-.01
I am very interested in examining what I think about	.77	.01	.70	-.03
It is important to me to try to understand what my feelings mean	.79	-.04	.78	-.14
I have a definite need to understand the way that my mind works	.73	-.03	.72	-.17
It is important to me to be able to understand how my thoughts arise	.72	-.02	.80	-.14
I am usually aware of my thoughts	-.13	.67	-.43	-.23
I'm often confused about the way that I really feel about things (R)	-.06	.79	-.18	.80
I usually have a very clear idea about why I've behaved in a certain way	.21	.66	.27	.60
I'm often aware that I'm having a feeling, but I often don't quite know what it is (R)	-.01	.66	-.13	.76
My behaviour often puzzles me (R)	-.16	.78	-.17	.76
Thinking about my thoughts makes me more confused (R)	.05	.65	-.03	.73
Often, I find it difficult to make sense of the way I feel about things (R)	-.06	.80	-.12	.87
I usually know why I feel the way I do	.07	.78	-.27	.63

Table 2: SRIS-SR and SRIS-IN Factor Loadings from two different studies (Grant, Franklin, & Langford, 2002)

Chapter 6: Findings

This chapter gives visual examples of created memory rooms, voluntarily shared by participants, and summarizes all major quantitative and qualitative findings. Qualitative findings are coded and quantified, then merged with quantitative findings to find overarching themes and use cases revealed by the participants' behaviours.

6.1 Subject Demographics

As discussed in 5.3.1, participants were limited to those trusted and geographically close to the researcher. Consequently, not only the number of samples, but also the diversity of participants suffered in some areas, such as gender, nationality, and ethnicity.

The average age of participants was 37.2, with the youngest being 15 years of age and the oldest 62. 16 out of 18 were German, the remaining 2 were Dutch. 6 participants were male, 12 female. Most participants fall into the typical bias one finds in low-budget research experiments at western universities, with the majority of subject being WEIRD, meaning raised in **W**estern, **E**ducated, **I**ndustrialized, **R**ich and **D**emocratic societies (Arnett, 2008).

16 out of the 18 participants had prior videogame experience. Those 2 who did not are among the oldest (ages 59 and 62) and experienced very little joy using the VR diary. 4 participants had prior VR experience; most having used it for games.

6.2 Voluntary Diary Insights

Several participants were willing to give some visual insight as to what they built during their testing period.

1. Figure 20 shows one interior design by a participant who used the VR diary for hours as a private retreat and during sleepless nights.
2. Figure 21 shows a stressful day.
3. Figure 22 shows a memory room by the same participant as the previous one, though the situation appears to have worsened.
4. Figure 23 shows the creative mix of real-life photos and 3D, in which it is not immediately obvious that the participant placed a photo of themselves behind the door, making it seem as if they were physically there.
5. Figure 24 shows the day of a subject who really likes butterflies
6. Figure 25 shows a room created by a professional gardener, who used the VR diary to experiment with interior design ideas.
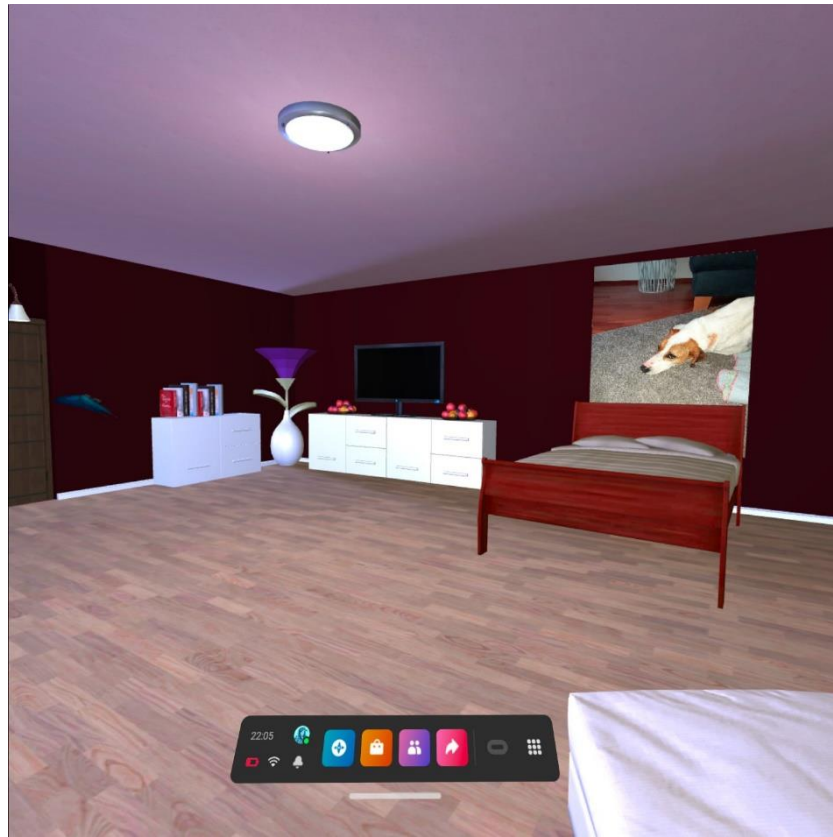
Figure 20: Memory Room screenshot 1, voluntarily provided by a participant
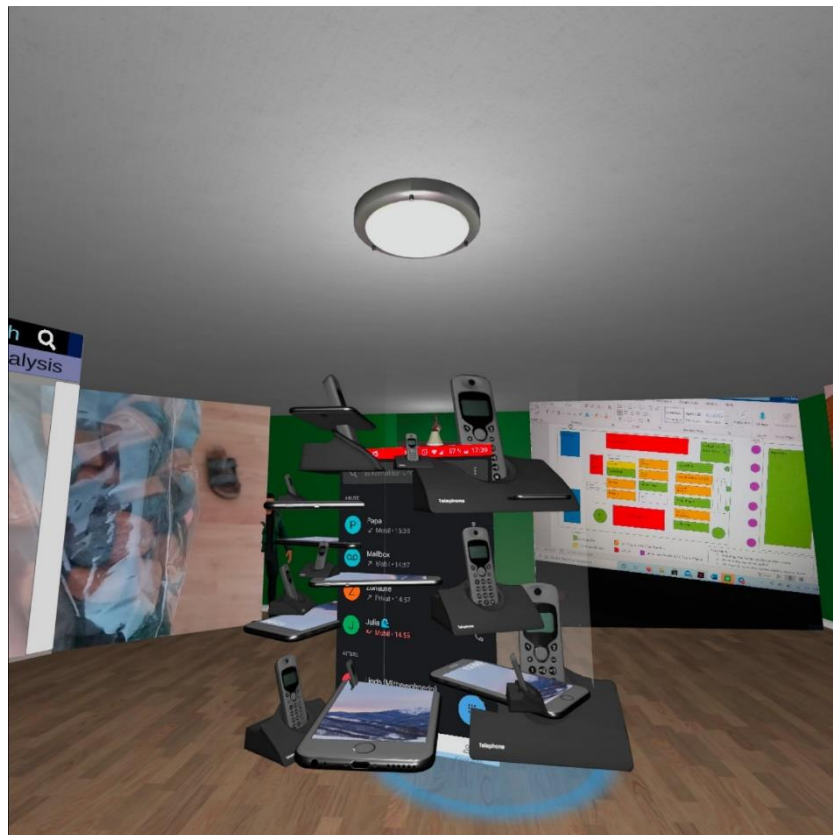
Figure 21: Memory Room screenshot 2, voluntarily provided by a participant

Figure 22: Memory Room screenshot 3, voluntarily provided by a participant
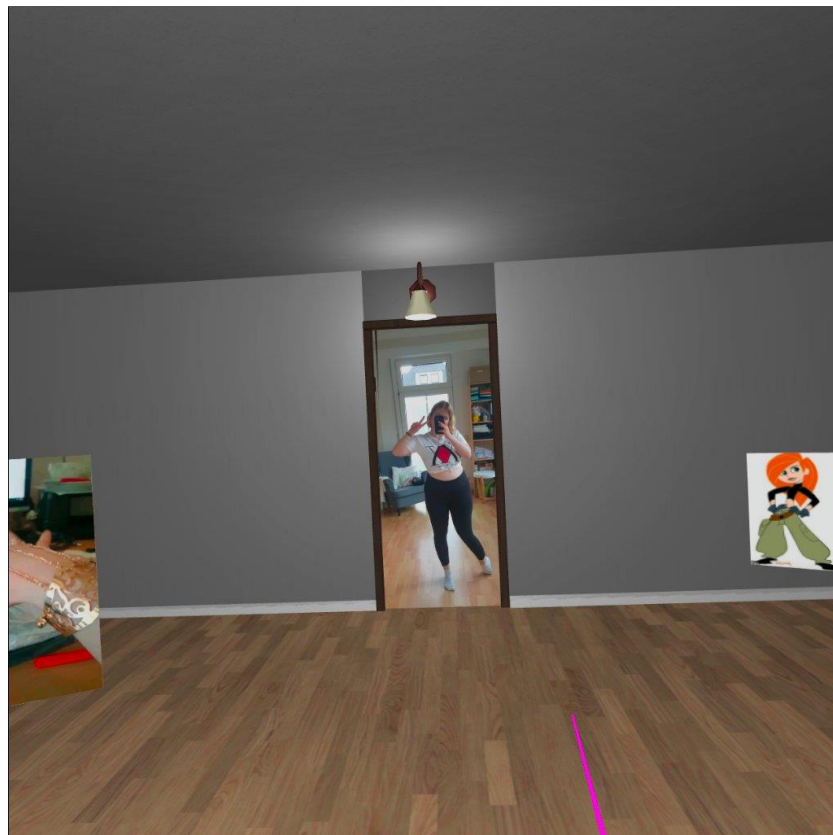
Figure 23: Memory Room screenshot 4, voluntarily provided by a participant

Figure 24: Memory Room screenshot 5, voluntarily provided by a participant

Figure 25: Memory Room screenshot 6, voluntarily provided by a participant

6.3   Individual Findings

Note: The uncompressed anonymized data (both from the metadata extraction and participant interviews) can be found at **https://github.com/TheRDavid/VRDiary**

18 subjects used the VR diary for a total of 91 days.

Table 1 shows media usage per subject, both the total amounts and averages per day. It shows clear favourites in terms of media usage.

#	Decorative 3D Models		Images		Videos		Voice Recordings		Plaintext		Audio Files	
	Total	Avg	Total	Avg	Total	Avg	Total	Avg	Total	Avg	Total	Avg
1	121	15.2	11	1.34	2	.25	0	0	4	.5	0	0
2	17	5.66	2	.66	2	.66	0	0	1	.33	0	0
3	19	6.3	4	1.33	2	.67	0	0	1	.33	0	0
4	149	29.8	11	2.2	3	.6	0	0	0	0	0	0
5	1	0.14	19	2.71	1	.14	1	.14	1	.14	0	0
6	2	0.29	17	2.43	0	0	5	.71	1	.14	0	0
7	0	0	42	7	5	.83	0	0	0	0	0	0
8	1	0.33	30	10	3	1	0	0	0	0	0	0
9	0	0	29	5.8	1	.2	0	0	39	7.8	0	0
10	34	8.5	13	3.25	1	.25	0	0	0	0	0	0
11	130	18.6	44	6.29	6	.86	0	0	0	0	1	.14
12	52	17.3	11	3.67	2	.67	1	.33	0	0	0	0
13	379	75.8	8	1.6	1	.2	0	0	0	0	0	0
14	257	51.4	10	3.6	3	.6	0	0	0	0	0	0
15	0	0	39	7.8	1	.2	7	1.4	0	0	0	0
16	13	2.6	22	4.4	3	.6	1	.2	2	.4	0	0
17	38	9.5	10	2.5	0	0	2	.5	0	0	0	0
18	131	18.8	14	2.0	1	.14	0	0	4	.57	0	0
	1344	14.8	344	3.78	37	.41	17	.19	53	.58	1	.01

Table 3: Total and average-by-day media usage per subject

Decorative 3D models were used the most on average, but unlike images, completely ignored or barely used by a third of participants. However, more than a third of participants used them extensively (placing more than 10 3D models per day). Images were used throughout by every participant, with much fewer outliers and is the favourite of media recording types by a large margin. Videos were occasionally used, by almost everyone at some point. Voice recordings and plaintexts were rarely used, but those who did try them out often used them multiple times. Only a single audio file that was not a voice recording was loaded into the VR diary.

Table 4 displays the SRIS values for each participant before and after testing. Note that only 16 out of 18 participants have recorded SRIS scores due to an organisational error during the research execution. Note that, while the average change in SRIS-IN is positive,

the total change in SRIS-IN is negative. This is due to individuals, most prominently subject 3, experiencing extreme changes due to a very low SRIS-IN value in the beginning.

#	Number Of Days	SRIS-SR			SRIS-IN		
		Before	After	Change	Before	After	Change
1	7	41.93	39.76	-5.2 %	24.43	23.47	-3.9 %
2	3	31.44	29.63	-5.8 %	20.44	22.73	+11.2 %
3	5	48.50	42.42	-12.5 %	12.94	23.66	+82.8 %
4	7	27.74	27.05	-2.5 %	22.15	22.43	+1.3 %
5	7	37.75	34.09	-9.7 %	25.35	23.92	-5.6 %
6	6	30.19	27.94	-7.5 %	25.72	26.69	-0.1 %
7	5	46.58	46.58	0 %	29.29	29.29	0 %
8	3	31.57	34.32	+8.7 %	24.65	24.30	-1.4 %
9	4	36.07	32.69	-9.4 %	24.99	19.75	-21.0 %
10	7	48.38	48.70	+0.7 %	26.40	22.53	-14.7 %
11	3	30.98	31.60	+2 %	23.63	21.12	-10.6 %
12	5	27.48	20.52	-25.3 %	21.72	25.74	+18.5 %
13	5	44.07	43.13	-2.1 %	18.20	21.94	+ 20.5 %
14	5	28.73	26.65	-7.2 %	25.68	27.57	+7.4 %
15	4	28.55	29.54	+3.5 %	21.53	22.09	+2.6 %
16	7	48.72	41.47	-14.9 %	23.09	20.10	-15.9 %
Avg	5.06	19.61	19.91	+1.5 %	31.70	29.89	-5.7 %

Table 4: SRIS Before and After Testing

Out of 1344 only 3 3D models were annotated with tags or descriptions, however 32.6 % of media recordings were annotated. This shows that a majority of memory recordings were meant to be self-explanatory, yet the option of adding tags or descriptions is necessary.

All but one participant used the VR diary only once a day. Usage times varied between 5 minutes and 90 minutes, with an average of 21 minutes. The most common timespans are between 11 and 27 minutes.

Positive and negative aspects pointed out by participants were coded and thus summarized and weighed by their frequency. Note that participants, after naming positive and negative aspects, were specifically asked for additional aspects that created any discomfort or difficulties regarding both the hardware and user interface.

Positive Aspects	Noted by
Encouraging creativity enriches the diary experience.	9 (50 %)
Multimedia enriches the diary experience.	8 (44 %)
Reflection with the VR diary is rewarding	6 (33 %)
The VR diary provides an escape from daily life.	5 (28 %)
The VR diary is easy to use.	5 (28 %)
The VR diary adds immersion, improving the experience.	3 (17 %)
Annotation data is useful.	3 (17 %)
The VR diary provides useful insights	1 (6 %)
The spatial dimensions add meaning to memories.	1 (6 %)

Table 5: Positive Aspects of the VR Diary (categorized)

Negative Aspects	Noted by
I felt physically unwell using the VR headset.	9 (50 %)
The VR diary is too time consuming	7 (39 %)
The VR hardware is a barrier.	5 (28 %)
The software is buggy.	5 (28 %)
There are insufficient design options.	5 (28 %)
The controls need improvement.	5 (28 %)
There are connectivity issues.	4 (22 %)
I would rather not use the VR diary daily.	3 (17 %)
I often don't create media content during the day and have little to insert into the diary	3 (17 %)
I want to be able to edit past days' rooms.	3 (17 %)
The VR diary is difficult to use	3 (17 %)
Not compatible with my phone	2 (11 %)
The visual quality could be better.	2 (11 %)
The spider model triggered fear.	1 (6 %)

Table 6: Negative Aspects of the VR Diary (categorized)

After noting the positive and negative aspects, participants were asked for further UX (User Experience) and UI (User Interface) issues, since many lessons are yet to learn for the implementation of VR diaries and VR user interfaces in general are yet to learn.

4 of 18 participants had issues with the 2D UI, like the media tablet on their simulated hand, pointing out they'd rather use more natural modes of object transformation than using a slider or limiting the amount of information displayed. A quarter of participants also suggested improvements to the user-controls, such as reducing the movement speed,

objects to automatically stick to walls, floors, and other objects, and designing object manipulation to be more efficient (at the cost of being less natural). Specifically, having to move to a specific spot in the room to place an object there was seen as laborious. Three more participants noted, again, that the hardware made them physically unwell, giving them headaches and nausea. Finally, three participants emphasized the need to shave off time and actions required to transfer media from their devices to the headset.

The overall acceptance rate of the VR diary was low, with a quarter of participants confirming they would likely use a VR diary long-term if they already owned the equipment. 18 % were unsure, the remaining 57 % confirming they had little to no interest of keeping a long-term VR diary. Reasons for participants to reject the idea of keeping a long-term VR diary range from the unpolished state of the software and lack of comfort of the hardware to the required time commitment and lack of enthusiasm for self-reflection.

All but one of those with little to no interest in a VR diary are also not keeping a conventional diary.

All but two participants left the Google services for voice transcription and advanced sentiment disabled.

In every memory room, for the duration of the respective day, participants were shown a selection window to rate their day's mood and VR diary experience on a scale of 1 to 5 (1 being bad, 5 being good). Figure 26 shows the average progression of the mood- and experience ratings. While the average mood shows the downward trend, the average experience improved towards the end.
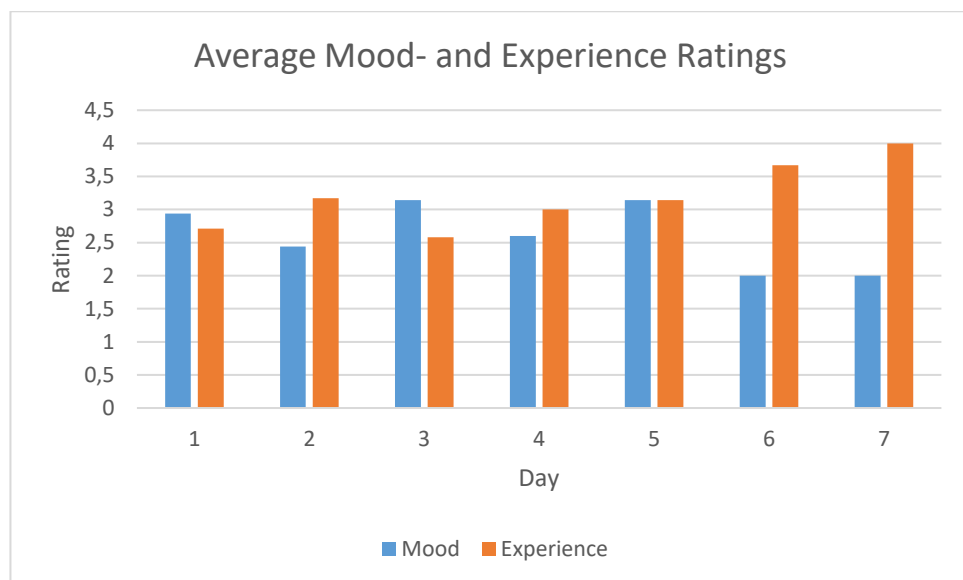
Figure 26: Mood- and Experience Ratings per Day (average progression)

The analysis tab (see Figure 17) only found occasional interest, with merely 3 participants actively using it, 4 noting they might use it to see trends over longer periods of time, 5

having entirely forgotten about or never found it and another 5 showing no interest (1 subject did not provide their answer sheet).

When asking those with diary experience to compare conventional methods to the VR diary, a lot of unique and insightful answers were given, which is why it was decided to quote each below, rather than coding and compressing them.

"With a diary on paper it's easier to write down long texts, but limited in terms of visual options. With a diary on paper there tends to be a coherent, specific topic, the VR diary gives more of an overview of the day."

"Can't even compare. This kind of VR Diary quickly develops its own dynamic. Being creative in the moment. Conventional diaries are more about listing things and events of the day and are much less creative."

"Multimedia in analog diaries requires higher effort and is impossible to this degree. But handwritten notes are more personal than plaintext."

"Same kind of burden due to time commitment. Didn't have to focus on language though and could let the memories speak for themselves, a quicker anchor to remember and a more colorful diary."

"VR version is much faster and easier to review. But it doesn't work as well for nuanced thought (especially when not using the mobile app). Also there isn't much to do when the day hasn't been eventful."

"In a conventional diary it's not easily possible to place videos / pictures and I really enjoyed the multimodal aspect of it."

"A bit more laborious, since multiple devices have to be used, for instance if you want to add something in retrospect, you have to go back to the app and then back again to the headset to add a memo or image, etc."

"These can't be compared. I use conventional diaries for writing long texts, that doesn't really work with the app."

"The 3D diary was more exciting."

"I'm using the Theme System Journal. This is really retro-actively thinking about the day instead of pro-actively creating media for the diary. I dont' naturally create enough media to fill the rooms, so it doesn't suit me."

"Conventional diaries are descriptive reflections of the day and events, the VR diary reflects the atmosphere, mood and momentary feelings"

To summarize the comparisons:

- Both variations have their own strengths, most notably the immersion, rewarding feeling and multimodality of building memory rooms in VR, as opposed to the fast and intuitive use of analogue diaries.

- The VR diary is generally used to record the atmosphere of the day, like an emotional snapshot, whereas analogue diaries are better at recording nuanced thought.
- The VR diary requires more effort.

Chapter 7: Discussion

This chapter will formulate and highlight takeaways from this experiment, based on the findings of the previous chapter. All the findings, and thus the following discussion, should be read with the fact in mind that the experiments' sample size of 18 is very small.

Nuanced, statistically significant correlations are hard to be found based on this data. There were also no obvious, clear correlations between aspects such as age, previous VR experience or previous videogame experience and grade of engagement or enjoyment. There was also no strong evidence for a positive impact of the VR diary on the keeper's SRIS values, though the usage time was rather short and, should there be an observable effect, it would likely only become noticeable over a longer period of time. Furthermore, subjects noted that the formulation of the questions for the SRIS scale are rather confusing due to some of the questions' wordings. Some questions also seemed repetitive and vague, which made it difficult to give confident answers.

The takeaways from this chapter are thus based on qualitative findings, such as reoccurring user experiences. In the following sections, the main shortcomings of this VR diary implementation and the main opportunities for future improvements are elaborated. In the last section of this chapter, these shortcomings and opportunities are translated into specific steps required for a majorly improved second version.

7.1 The Main Issues

While many subjects recognized the potential of VR diaries, nearly half complained of headaches and nausea, limiting the time they were willing to spend in the simulation. Physical irritations were the number one complaint. Others noted they felt the VR hardware itself put a barrier between them and the diary. The fact that longer time spent in the diary led to more intense discomfort may explain why nearly no one thought to place music or any other kind of audio elements (beside voice notes) in the memory rooms. It is not yet a place in which one can relax. Certain precautions can be taken to limit user discomfort, such as easing into movement rather than rapid acceleration and implementing an alternative mode of travel to walking, such as teleportation. Still, the first main issue remains:

1. **Leaps in user comfort will only come with lighter, more comfortable devices and better motion tracking**.

Related to hardware complaints is the issue of effort. Multiple participants noted they'd rather not use the VR diary daily, but on a weekly, or some other time basis. It was clear from the beginning that the number of steps a user has to take and the number of seconds that pass from when the user wants to use the VR diary to the moment when they enter the memory room, will need to be reduced as much as possible. No matter how polished and optimized the usage process, it is going to take significantly longer than a conventional diary. However, if these extra efforts would occur on a weekly basis, rather

than daily, they would not be as much of a bother. To use an analog diary, one has to open a book and grab a pen. To use the VR diary, given that the user has taken recordings over the course of a day or week, they have to…

- Make sure their mobile device is connected to the same Wi-Fi as the headset
- Queue any memory files on their phone that were not created with the companion app for transmission
- If turned off, turn on the headset (wait for it to boot)
- Navigate to the custom installation menu (as this is not an official app and is thus not displayed in the home menu)
- Launch the VR diary
- Potentially wait for the data transfer to be completed

Despite all efforts, the second main issue is:

2. **The current process of memory data transmission and VR diary launch takes too long and requires too many steps.**

This is especially true in the evening, when users will likely wish to relax, not struggle with technology. Furthermore, VR is still not user-friendly. Both the VR diary implementation and VR hardware are to blame. There were many design issues uncovered by users, such as the need for more polished object manipulation mechanics, like objects snapping to each other, or the ability to place objects in places out of reach of the subject. The initial intent behind making users walk and physically place objects, as they would do with their hands in the physical world, was to make the interface more immersive and to imitate real world mechanics. However, this does conflict with the idea of the VR adding improvements to real-world like experiences, like offering unlimited space and the ability to furnish an entire room in seconds. The takeaway is the main issue number 3:

3. **Implementing real-world limitations adds more frustration than immersion**.

Lastly, one issue that will also find its way into the section on opportunities, is the aspect of fun. Many participants noted that, while it was fun to feel creatively empowered, they felt limited at the same time. The selection of 3D models to place was not large enough, the models themselves too simplistic or poorly designed and clearly did not fit together (as they were scavenged by the researcher from free online resources). Design options were fun, but limited as well, users could not change the geometry of the room or paint on the walls and surfaces themselves. One participant noted that the experience could be greatly improved for them if the location itself could be changed, from a plain room to a forest or a space station, or any other place with greater atmosphere. To summarize, the fourth main issue is:

4. **A graphically higher quality, more feature rich implementation would go a long way to make the VR diary more attractive**.

This could also solve situations in which users did not record any memories throughout the day, yet still want to reflect on it (see Table 6).

7.2   The Main Opportunities

An advantage of the VR diary that was pointed out very early on is its focus on creativity. Where conventional diaries are often written like reports or lists of events, the VR diary forces the user to think creatively from the very beginning, when it comes to spatially arranging the memories. Even when ignoring all the decoration- and design features, the mere placement of memories conveys meaning, in how they spatially relate to each other. As a participant put it:

1. **The act of building rather than writing down memories is creatively stimulating and rewarding**.

The retrospection when walking through old memory rooms was thus more rewarding, as they are hand-built, rather than written down. Where conventional and more linear diaries are made for documenting complex, nuanced, and carefully worded thoughts, the VR diary exceeds in conjuring a certain atmosphere. The media usage statistics show that, while not used by everyone, the majority of placed objects were 3D assets. This can partially be explained by the playfulness enjoyed by participants when decorating and designing, but a part of that is also owed to the fact that atmosphere matters. In general, participants were keen to make the VR diary their own and give it their individual personal touch, with many of the complaints being that there weren't enough options for decorating, designing, and selecting environments. While every conventional diary is certainly unique in its written content, the second main opportunity of the VR diary is the fact that

2. **Not only the memories, but the medium itself tells a story**.

The VR diary turned out to be an extremely flexible tool that could be used in a lot of very different ways. One participant used it to let loose her creativity, as she likes spending time designing interiors. It became her experimentation chamber, where she could effortlessly document her ideas by putting them into action. Another participant spent hours at a time in the VR diary during sleepless nights. To her, having a completely isolated space just for herself offered a private retreat she hadn't realized she needed. One participant who works in a senior residence suggested its use for therapeutic purposes. Yet other participants simply used it as a conventional diary.

To summarize: The VR diary, in its core mechanics, is not that different from conventional diaries. However, it does offer a more interactive, immersive, and visually rewarding alternative, adding not only a spatial, but also artistic dimensions and will reflect the user not only by content, but by form and function as well.

7.3   The Steps for creating a better VR Diary

This section first turns the previously discussed aspects and translates them into explicit steps to solve or at least alleviate the issues and further build upon the strengths and opportunities.

Issue: Leaps in user comfort will only come with lighter, more comfortable devices and better motion tracking.

This is a problem that, over the next years, will mostly be solved by hardware manufacturers, as they will manage to produce more powerful devices with smaller and lighter hardware. Given the current speed of development, a successor to the Quest 2 will likely be available by the time an improved VR diary is finished. Still, until that happens:

Action: Software solutions can alleviate this issue by implementing gentler, less nauseating motion and reducing the required time spent in the VR diary to experience its benefits. Optimizing user procedures leads to the next issue as well:

Issue: The current process of memory data transmission and VR diary launch takes too long and requires too many steps.

The mere fact that this VR implementation was made for a research study in some ways worsened the experience for users. As the VR diary handles very private data, its security was of high concern, especially given that the experiment procedure had to be approved by an ethics committee. To ensure data security, memories were never sent from the participants phones to the headset via the internet, but through direct Wi-Fi connections. This leads to issues when specific Wi-Fi setups used amplifiers or mobile phones that were configured to use mobile data, leading to participants having to change configurations for the transmission to work. Furthermore, the pairing of devices over Wi-Fi turned out to be the bottleneck for transmission speeds, as the actual transmission happened very fast, but sometimes only after a long waiting period until the devices finally managed to pair. Furthermore, many participants experienced connectivity issues, when their phones did not manage to pair with the headset at all. These issues would not be nearly as prevalent in a commercial setup, where the user data would be transferred and processed via a dedicated server. Most connectivity issues would not have occurred in such a setup and the data processing would not need to be handled by the VR device, which would shave off more time between data transmission, processing and receiving.

Thus, the **Action:** Switch from peer-to-peer file transmission to using a dedicated server to handle sending and data analysis.

Another design opportunity would be for data to be pulled from the phone by the headset, rather than being pushed by the phone to the headset. An implementation that allowed the user to browse their phone data from within the headset, to then select the memories they'd like to place in the VR diary, would mean users would no longer have to switch back-and-forth between the two devices in case they forgot to transmit a certain file. This,

of course, would again mean that the user's phone data would be accessible from the headset through the internet, which may raise privacy concerns.

Action: Implement data pulling from the headset, as an alternative to data pushing from the phone.

Lastly, the off-loading of data processing from a local Android device to a dedicated server would allow for advanced data analysis, such as the processing of voice commands or facial recognition in video. To summarize: The data transmission could be much faster and require further user steps, however the user would need to trust the developer to protect their privacy, as it is no longer in the user's hands. It would also enable more processing-heavy data analysis.

Issue: Implementing real-world limitations adds more frustration than immersion

A lesson learned from this experiment is that, while immersion and simulated physical presence add to the user excitement, it is not as important as convenience. As much fun as it can be to stroll through past memory rooms, it is not fun having to walk to a specific spot to place an object there, especially given the physical complaints that often come with movement in current-gen VR hardware.

Action: More efficient tools that reduce time spent on repetitive tasks, such as placing 3D objects, should be implemented in an improved VR diary, for instance:

- Being able to manipulate objects from a distance (maybe akin to telekinesis, as a fun tool)
- Teleporting as a faster alternative to walking
- Objects magnetically snapping to each other, to walls, ceilings, and the floor.

Action: Take inspirations from existing editor tools, such as Unity, Unreal's VR Editor, and games such as Sims.

Issue: Graphically higher quality, more feature rich implementation would go a long way to make the VR diary more attractive.

Trivial, yet not easy to implement: Participants want to be immersed in more exciting environments than the graphical equivalent of a 20-year-old videogame. This implementation suffered from its low budget, as all 3D models are ill-fitting free online assets, and the surroundings (plain memory rooms) were hurriedly built by a single person with no background in graphics design or 3D modelling.

Action: An improved VR diary requires some funds and extra manpower to create visually stunning and more immersive environments that users would be excited to spend time in.

Opportunity: The act of building rather than writing down memories is creatively stimulating and rewarding.

Action: More time and a larger team (than one) should be invested to further boost users' creativity, by implementing more features, customization options and empower the user to make the VR diary their own. Again, inspirations should be taken from existing desktop-tools that allow the designing of environments.

Furthermore, the feeling of reward should be strengthened by giving automatic feedback to the user, much like achievements do in video games. The user can be complimented for having built a large VR diary with a certain number of rooms or for storing a certain number of memories. The diary could even comment on the memory contents, though it should not overstep boundaries or pass any kind if negative judgement. Further user research should be conducted to explore this aspect.

Opportunity: Not only the memories, but the medium itself tells a story.

With this small sample size alone, three distinct usage motivations emerged:

- Diary keeping
- Personal retreat
- Creative playground

The openness and malleable nature of the VR diary should be embraced and as few limitations as possible should be placed on the user. One limitation that was placed to prevent participants to change past memory rooms, was the ability to only the room of the current date. This limitation was met with annoyance and irritation by the participants.

Action: Do not enforce a *correct* way of using the VR diary, embrace freedom of choice.

For instance, not only allow the user to edit past memory rooms, but also allow them to mix rooms, or even change the way rooms are arranged. Users should be given the feeling that they can't do things wrong. Especially with older subjects, the question of "*Am I doing this wrong?*" was raised frequently, leaving them feeling stressed and anxious when confronted with this new kind of technology. In an opposite example, one elderly subject, after failing to select an object, dropped all caution and began pressing random buttons, laughing as the surroundings changed as a result. With that attitude, she mastered the VR diary after only one day of use and ended up placing over a hundred different 3D objects in her rooms.

Action: Do a large user-test with more participants to find further ways the VR diary is used and empower those newfound ways in the improved implementation.

There may be interesting modes of use already employed in some of the similar apps explored in Section 2.4. At the same time, a balance must be found so that an open, more feature-rich implementation does not turn into a fragmented universal VR tool that loses its core idea of empowering creativity and self-reflection.

To summarize: Stepping into a person's VR diary should be an immediately unique and personal experience, to a higher degree even than stepping into a person's living space.

A last opportunity that was not explored in this experiment, is that of VR diary sharing. Through VR, people can be present in distant places and seemingly physically together when far apart in the physical world. It could be a very intimate way of getting to know one another when people could invite each other into their VR diary. This would, of course, require a lot of trust placed by the host into the guest, and user controls to limit what a guest could see (e.g., locking specific doors that only the host can open). A VR diary may provide an entirely new way of sharing memories and a future implementation or research effort could offer interesting insights in bonding or getting to know one another through physical presence in a shared memory room.

Chapter 8: Conclusion

This chapter summarizes the most important lessons learned, gives a review of this research and an outlook on future work.

8.1   Research Questions – Answered

How to design a VR diary that allows people to generate value for themselves?

A VR diary must be as gentle and seamless as possible. The most critical and frequent complaint, often a deal-breaker, is how uncomfortable the headsets are. When not distracted by flashy interactive games, users will often feel headaches, nausea, and poorly sitting hardware. A VR diary must make wearing the headset as bearable as possible, although future VR devices will likely address this problem.

A VR diary must offer a lot of functionality for customization and creativity, as it needs to justify the higher amount of effort required with a higher reward.

A VR diary must also be flexible, to allow the creation of diaries as unique as their users.

A VR diary with broad appeal is possible, though it was not achieved in this project. The potential of it was however apparent and I am more confident than I expected to be that, with a new generation of VR headsets and an implementation that learns the lessons from this experiment, a broadly appealing VR diary can be created. Nearly all the deal-breakers and major flaws in this experiment are easily fixable and owed to the early stage of the hardware, low manpower, non-existent funding and experimental nature of this first attempt.

8.2   Review

Exploratory in nature, this project was mostly me throwing ideas at the wall and observing what sticks. There are the obvious lessons to be learned and aspects where, in retrospect, wiser decisions could have been made.

- Aside from the short-term (4-7 days) experiments, one or two long-term experiments (14 days and longer) could have been conducted to get a better idea of long-term user experiences.
- Help from other students or friends could have been requested to alleviate some of the implementation efforts, reducing stress and freeing more time for testing and bug-fixing.
- More inspirations from existing videogames and editor tools could have been taken to improve the user experience of the spatial arrangement tools.
- A more diverse pool of subjects would have been desirable.

Much like the 40% of researchers employing diary methods that Jannsens et al. (2018) found to be dissatisfied with their method, I too would design it differently if I were to do

it again. I would intensify the study by lengthening the testing periods, but relax it in the short term, allowing subjects to skip days, yet still add them in retrospect, or combine them in a week-based memory room.

Most of these "lessons" are fairly obvious and simply boil down to "a less frantic and more thoroughly planned approach would have been advisable". However, this will likely be the case when doing experimental research with a high demand in effort and low amount of time and manpower. A lot of decisions were made very abruptly to move on to finishing the implementation and a more thoughtful and planned approach would have required significantly more time. Overall, this project feels in many ways like an alpha-test for a more serious and thorough approach, a more focussed, less frantic, and more polished research project.

I am generally very content and think that a good trade-off was made between having more thorough research and a more polished implementation or getting a finished version into the hands of test-subjects as fast as possible. More thorough preparation will likely have resulted in a better user experience and higher acceptance rate, but even with this rather rushed attempt, lessons were learned almost immediately that rendered weeks of preparations obsolete, as for instance the implementation effort that went into providing speech-to-text features that not a single participant ended up using. Given the nature of this research, a "fail fast and learn fast" approach is advisable.

8.3   Contributions

This work explores multiple new branches of research for virtual reality and contributes a broad range of findings and lessons for this specific type of VR experience design.

- This work shows some of the creative and naturally evolving uses of a playground-like VR diary.
  - A diary-tool
  - A private retreat
  - A therapeutic tool
  - A design playground
- This work found that these types of use-cases will be discovered, rather than purposefully designed beforehand (thus, more research will be required to find new use-cases outside of those 4 found).
- It was found that users want to be creative; they want to make the environment and even the way the diary functions their own. VR diary users do not want to be constrained by artificial limits or told how to use their VR diary. They want to explore what is possible and will spend time with certain functionalities, while often completely ignoring other parts of the experience.
- It was found that diary users want to re-experience their own stories and be rewarded for building their memory rooms.

- This work found a lot of promise in the concept of a free-form, creatively empowering VR diary, the implementation of which will need to learn the lessons discussed in the previous chapter.
- The implementation, while not advised to be used directly, provides a base to start a more advanced project. This entire project is hosted on GitHub: https://github.com/TheRDavid/VRDiary

8.4 Future Work

There is work to be done both in terms of research and implementation.

The actions outlined in the previous chapter should be taken, however, at this stage, the participation of a professional UX or UI designer would also go a long way, as this implementation was functional and intuitive enough, but not exactly "good", as the interactions lacked polish and the UI lacked visual appeal.

Should waiting for future updates to the hardware of standalone VR devices be out of the question, then implementing the VR diary for tethered headsets is worth an attempt, as they may be less mobile, but more geared towards a high-end experience, not only in terms of wearing comfort, but also available processing power, thus enabling the simulation of more visually appealing environments.

Research efforts, based on the improved implementation, should go into a more detailed analysis of features used and wished for, while more broadly exploring emerging user stories. Unlike most software, where a user clearly wants a specific result, to be achieved by following a predetermined set of steps, many user stories of the VR diary are still unknown. To find them, user activity in the VR diary should be more closely monitored (for instance which features are often used together) over a longer period. Additionally, users may be more closely supervised to enable them reaching their goals. There are likely also user behaviours that need to be visually recorded to reveal their user story. All these efforts however will need to walk a fine line between thorough research and and invasion of privacy.

There is also, as discussed at end of the previous chapter, the completely unexplored potential of VR diary sharing. Will the simulated physical presence of others in one's diary lead to an intense and intimate exchange of memories, thoughts and feeling? Or will it turn the intimate nature of the diary into a hollower and more performative version of itself, more like current social media platforms?

Glossary

3DoF: Three degrees of Freedom (3DoF), in the context of virtual reality devices, describes thethree types of movement the device can tracK: Rotation in three dimensions (pitch, roll, yaw).   7

6DoF: Six degrees of Freedom (6DoF), in the context of virtual reality devices, describes the sixtypes of movement the device can track: Movement along all three spatial dimensions, aswell as rotation in three dimensions (pitch, roll, yaw)   7

Augmented Reality (AR): Augmented reality describes a mixed reality in which a visual layer of virtual objects is placedon top of a visual of the physical world.   8

FFmpeg: Fast Forward MPEG is an open source library with a command-line interface that allows for the processing of and conversion between different multimedia formats   27

Interial Measurement Unit (IMU): An interial measurement unit measures a body's motion andphysical state, through the use of accelerometers and gyroscopes. Smartphones additionally use magnetometers as a means to measure a body's direction relative to the magnetic lines,but those are of no concern in the context of VR.   8

IPD: The interpupillary distance is the distance between a person's eyes. The IPD is relevant in VR, since people are used to seeing two different images that are slightly different in their point of view. A larger IPD leads to a larger difference and vice versa, which needs to be accounted for by the VR device to display a realistic looking image and avoid causing headaches and nausea.   19

Mixed Reality (MR): Mixed Reality is an overarching term for the mixing of the physical and avirtual reality. There are different types of Mixed Reality, such as AR and VR.   7

NUI: A natural user interface (NUI) is one that is generally not noticed by the user, as it is intuitive enough to be used without consciously thinking about it.   21

References

PCM: Pulse-code modulation is a form of audio data storage. It represents analog signal samples. Unlike compressed formats such as MP3, PCM is as close as possible to the original analog sound. 27

SQLite Database: A SQLite database is a standalone database, meaning it does not require extra software to be installed on the host system. While the feature set is limited compared to conventional databases, it does allow for basic SQL queries. SQLite is the default choice for simple local databases on Android systems. 27

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Appendix A: Preliminary Test Interview Protocols

	Subject 1	Subject 2
Days participated / total days	9 / 14	5 / 9
Were some of these days particularly interesting?	Yes, there were extreme mood swings and life drama	All rather average days
Is that reflected in the recordings	Yes	Probably, they reflect the Corona situation, which is the new normal
How many files did you accrue?	Roughly 10 per day	Roughly 3 per day
How many of each filetype?	Per day: - 3-5 pictures - 1 video - 1 song (or playlist) - 3 colors - A handful of links (for instance YouTube)	About 3 photos per day
If there are none of a certain type: why?	Usually there would be WhatsApp voice notes, just coincidentally none this week	Voice notes are strange for them, they might consider them if they were not working anymore. They require more effort than photos. They only took photos because they are the fastest, easiest, least effort and most convenient. There is no need to plan for them or be in private. They also helped in remembering the context, not only the moment.
Which filetypes are the most or least convenient?	Most: Pictures, videos, voice notes	Most: Photos
Are there any very large files?	Videos	Photos
How much time did you spend on this experiment per day?	No addinional time, as taking these kinds of recordings was already part of their daily routine.	About 5 minutes
What are your recordings about?	Things they enjoy, like hobbies, things related to their own body and food. Nothing work related.	Anything. Social matters were of highest importance. Corona.

		Work and hobbies might be important in their moments but will likely blur over time. Pictures of newspaper articles that reflected their state of mind to some extent
Could you imagine doing this for a longer period of time?	Yes, but maybe not every day.	Not now, maybe if they became more forgetful in older age. At the moment they are too busy and would also rather live life than spending time recording and reviewing it.
Would you enjoy reviewing the recorded content afterwards?	Yes	Yes
Are you keeping a diary at the moment?	No, except for a mood tracker	No
Have you kept a diary in the past?	No, tried and "failed", however for a while they did one drawing a day as a similar ritual.	In their mid-fourties when they were having a difficult time. It was therapeutic.
What were your recording devices?	- Smartphone - Color bars on paper - Webcam	- Smartohone
Were your recordings important to you?	Some, most of the repetitive ones less	Not sure, priorities and meanings change
Do you think browsing your interesting (long-term) memories could be valuable in a few months time?	Yes, though it depends on how it is done. They do not like it when their phone is "preachy" or pretends to be a person by reminding them of past photos etc. As an alarm-like or integration into existing apps (WhatsApp-bot): yes	Yes
Would you like it if your phone prompted you once a day (or every other day) with questions regarding you day and mood?	Only if she could ignore/dismiss it without opening the app	No, maybe if she grew very forgetful
How would you feel if your content was analysed by a software, but without showing any of your private data to anyone else (with the software only showing analysis results to you)?	Would need to see the value of that. They do not want a software to make wrong assumptions and try to be too smart. Rather they want to use the software as a tool to query data and draw conclusions about themselves by themselves.	Very unpleasant
How would you feel if some of that data was analysed online, given that it is deleted from the	Same as above.	Her own privacy would feel out of their control, and they wouldn't know who has access.

server right after the analysis results are returned to your device?		
What else would you like to note about this test?	This test made them feel like a vlogger and vaguely reminded them of the project "This day 2020 time capsule"	They would easily forget to do this daily and would need to make it a ritual.

	Subject 3	Subject 4
Days participated / total days	5 / 5	5 / 6
Were some of these days particularly interesting?	Yes	Overall uneventful
Is that reflected in the recordings	Not sure	Probably not
How many files did you accrue?	This varied greatly between days, they do not remember the precise number.	A lot of audio recordings
How many of each filetype?	There were - Screenshots - PDF documents - Zip archives containing power points - Daily search histories (as HTML) - Plaintext - Images - Websites - Audio - Video	Mostly audio, few texts
If there are none of a certain type: why?		Too much effort for the others
Which filetypes are the most or least convenient?	Most: Screenshots and other files they already have (do not need to record)	Most: - Audio - Video - Photos Least: - Text
Are there any very large files?	Videos of around 1 GB	No
How much time did you spend on this experiment per day?	About 10 minutes	About 3 minutes

What are your recordings about?	Anything, though the focus lies on work and hobbies	Mostly work and hobbies and achievements. Aesthetic things, like a nice walk during sundown Less social interactions due to COVID.
Could you imagine doing this for a longer period of time?	Yes	Having a neat app would be nice.
Would you enjoy reviewing the recorded content afterwards?	Yes	Yes, especially long-term content.
Are you keeping a diary at the moment?	Yes	No
Have you kept a diary in the past?	Has been keeping a diary for most of the last decade	Attempted a couple of times
What were your recording devices?	- Smartphone - PC	- Smartphone
Were your recordings important to you?	Very important, as they are an introspection enthusiast	So and so
Do you think browsing your interesting (long-term) memories could be valuable in a few months time?	Yes	Yes
Would you like it if your phone prompted you once a day (or every other day) with questions regarding you day and mood?	Likes the idea, but has made bad experiences with implementations of it, where the question were boring and surface-level	No
How would you feel if your content was analysed by a software, but without showing any of your private data to anyone else (with the software only showing analysis results to you)?	Would need to be given a good reason	Would want to know their rights, but if it isn't stored somewhere else it would be okay.
How would you feel if some of that data was analysed online, given that it is deleted from the server right after the analysis results are returned to your device?	Fine if safety is guaranteed	See above
What else would you like to note about this test?	Finds it interesting to keep their life in file-shape	Being able to read voice notes would be fun. Past experiences with diaries made them hesitate to participate.

	Subject 5	Subject 6
Days participated / total days	9 / 16	8 / 10
Were some of these days particularly interesting?	2 of them were interesting	A birthday was interesting
Is that reflected in the recordings	Yes	The more interesting the day the fewer recordings, as they were too busy experiencing the interesting things of that day. There is also a bias towards negative emotions, they were more likely to take note of those
How many files did you accrue?	4-5 a day on average Up to 20 on exciting days	3 a day on average
How many of each filetype?	On average - 1 screenshot - 2 photos - 2-3 text notes - 1-2 articles - 2-10 voice recordings	Mostly pictures, some voice recordings and text messages
If there are none of a certain type: why?	No videos, as they are not in the habit of taking them. Mostly because they have storage and camera issues.	Videos did not come up, but for no particular reason
Which filetypes are the most or least convenient?	Texts are easiest to skim through	Easiest to create: Voice recordings Easiest to recap: Pictures
Are there any very large files?	Photos	Photos
How much time did you spend on this experiment per day?	No addinional time, as taking these kinds of recordings was already part of their daily routine.	About 5 minutes
What are your recordings about?	Monitoring progress (for instance learning a new song) Dreamjournal Events of the day Mood boards for projects (work) Art they liked or created Social interactions (audio recordings)	Everyday stuff, work, corona, hobbies

Could you imagine doing this for a longer period of time?	Yes	Open to the idea
Would you enjoy reviewing the recorded content afterwards?	Yes	Yes
Are you keeping a diary at the moment?	Yes (phone and conventional paper one)	No
Have you kept a diary in the past?	Yes, most of their life	No
What were your recording devices?	- Smartphone	- Laptop
Were your recordings important to you?	Most are important	Some were important long-term Most were important short-term
Do you think browsing your interesting (long-term) memories could be valuable in a few months time?	Yes	Yes
Would you like it if your phone prompted you once a day (or every other day) with questions regarding you day and mood?	Sometimes, but not overbearingly	Helpful, but only if there was no loading time or app-change involved
How would you feel if your content was analysed by a software, but without showing any of your private data to anyone else (with the software only showing analysis results to you)?	Maybe for transcription of voice notes	Kindof creepy
How would you feel if some of that data was analysed online, given that it is deleted from the server right after the analysis results are returned to your device?	Optional	Would opt out
What else would you like to note about this test?	Was annyoed on certain days when nothing noteworthy happened. Could be eliviated by question prompts. Thinks there is therapeutic value (having a ritual, shifting point of view, remembering what to be thankful for	The tool sounds helpful. Spatial collections are likely to help browsing through large collections of content. Would generally opt out of data-sharing. Would rather do it spontaneously than regularly.

	Subject 7	Subject 8
Days participated / total days	5 / 8	3 / 3
Were some of these days particularly interesting?	Some	Not sure
Is that reflected in the recordings	Yes	Not sure
How many files did you accrue?	14 in total, unevenly spread	16 in total, unevenly spread
How many of each filetype?	Voice recordings Documents	Day 1: 8 photos + 1 video Day 2: 2 photos + 3 videos Day 3: 1 photo
If there are none of a certain type: why?	No videos due to bad phone camera. Might use dedicated camera, though extra step for transmission would be bothersome	No voice recordings because voice-note app on phone doesn't work (would want that function baked into the companion app)
Which filetypes are the most or least convenient?	Most: Photos and pictures from the web Videos (Instagram stories)	Photos are very convenient
Are there any very large files?	Not sure, but used roughly 1.7 MB a day	
How much time did you spend on this experiment per day?	Less than 15 minutes	Less than 10 minutes
What are your recordings about?	Work, free time, mental state, goals	Casual everyday things
Could you imagine doing this for a longer period of time?	Yes	Yes, but not daily
Would you enjoy reviewing the recorded content afterwards?	Yes	Probably not, rather use it as a tool for the moment
Are you keeping a diary at the moment?	Yes (occasionally)	No
Have you kept a diary in the past?	Yes (occasionally)	No

What were your recording devices?	- Smartphone - Laptop	- Smartphone
Were your recordings important to you?	One elaborate piece of writing is important long-term	Not really, also would like to be able to remove unimportant items quickly
Do you think browsing your interesting (long-term) memories could be valuable in a few months time?	Yes	Maybe, maybe not
Would you like it if your phone prompted you once a day (or every other day) with questions regarding you day and mood?	If they don't have to type, yes	Would be helpful to remember to make a recording
How would you feel if your content was analysed by a software, but without showing any of your private data to anyone else (with the software only showing analysis results to you)?	Offline analysis would be fine	Not interested
How would you feel if some of that data was analysed online, given that it is deleted from the server right after the analysis results are returned to your device?	Would want to decide case by case	Would need to be clearly defined, then maybe
What else would you like to note about this test?	- Social media integration might be useful - The integration of stickers is of utmost importance - Photos taken with camera are of higher importance than web-images - They liked sitting down once everyday for a few days in a row and spend time reflecting as a ritual - They liked the idea of adding pictures in a diary, had not considered that before - Aesthetics are important, would like to have tools to make it look pleasing - Might also use as a to-do list	

Appendix B: 3D Assets References

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